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The hagfish

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On the cover: A hagfish (right) and a greenstriped rockfish (left) swim near a sea urchin off the Oregon coast. See the article beginning on page 19.

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A Review of Recent Developments in the World Sea Cucumber Fisheries

CHANTAL CONAND and MARIA BYRNE

ABSTRACT—Sea cucumbers (Holothuridae and Stichopodidae) have been harvested commercially for at least 1,000 years. The world fisheries for sea cucumbers, however, are not well documented and in general are poorly managed. Depending upon the species exploited, there are two processing procedures for the sea cucumber product. Some species are eaten raw, while most commercial species are processed into a dry product called bêche-de-mer or trepang. This dry product is exported to a central market such as Hong Kong and then re-exported to the consumers. In this review, recent statistics on the world sea cucumber fisheries, collected from different services, are detailed for each major fishing area. Case studies for each fishing area are also presented. Recent major changes in the Indo-Pacific fishery include the participation of new producer countries, the shift in the species being exploited, and an increase in the Chinese market. The expansion of the largely monospecific temperate North Pacific fisheries is also described. Statistics from Hong Kong, Singapore, Taiwan, and the Food and Agriculture Organization provide valuable information on the producer and importer countries. Particular attention is paid to the reciprocal trade of bêche-de-mer between Hong Kong and Singapore. An evaluation of the world sea cucumber landings and bêche-de-mer production is presented. Recent developments include an expansion of the Hong Kong market due to increased demand by China, the importance of Indonesia as a major world producer, and an increase in the fisheries of Tropical Pacific nations. This increase is best documented for New Caledonia and Fiji. Ways to improve the access and the reliability of the statistics for the sea cucumber fishery are discussed, as is the potential for management of artisanal fisheries.

Introduction

The commercial exploitation of marine invertebrates has received increased attention during recent years, and progress has been made in the knowledge of stock dynamics and fisheries management, particularly for crustaceans and mollusks. Although invertebrates yield lower landing weights in comparison with finfishes, their high economic value compensates for this difference, with invertebrates accounting for nearly 40% of the value of the world fishery trade (Caddy, 1989). Invertebrates also play an important role in the structure and function of marine communities. On coral reefs, for example, echinoderms are main components in the food chain at various trophic levels and play an important role through grazing, predation, or bioturbation (Birkeland, 1989).

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Echinoderm fisheries are generally small in scale. Sea urchins are exploited for the roe, and sea cucumbers are harvested for the body wall, longitudinal muscles, and viscera. World statistics from these fisheries have been reviewed for the years 1978–86 (Conand, 1989a; Conand and Sloan, 1989). The recent growth of the North American red sea urchin fishery has raised the question of the feasibility of stock enhancement to maintain the fishery (Tegner, 1989).

Holothurian fisheries are based on a few deposit-feeding species belonging to two families and five genera: *Actinopyga* and *Holothuria* (Holothuridae) and *Parastichopus, Stichopus,* and *Thelenota* (Stichopodidae). The few species exploited amount to about a dozen amongst the thousand existing. Sea cucumbers are eaten either raw, boiled, or pickled. In Japan and Korea the body wall and viscera of sea cucumbers are eaten raw or pickled (Mottet, 1976; Conand, 1986). The most important sea cucumber product, however, is the dried body wall which is marketed as bêche-de-mer (Fig. 1), also called trepang or hai-som, throughout the tropical Indo-Pacific (Conand, 1989a).

Processing methods for bêche-de-mer, believed to have been introduced by Chinese traders, include six stages: Boiling, slitting the dorsal side, second boiling, gutting, smoke drying, and sun drying (Conand, 1986). These procedures vary according to the species processed. Processing considerably reduces the length and weight of the sea cucumber, and the final product weight is about 10% of the original weight (Conand, 1979; Vuki and Viala, 1990). This factor must be considered when comparing landings data with bêche-de-mer production.

Bêche-de-mer is exported from the producer countries to a central market such as Hong Kong or Singapore, and then is re-exported to Chinese consumers. These fisheries are of economic significance, particularly in developing countries. Bêche-de-mer as an export product can fetch high prices (US$25/kg for first grade products). The bêche-de-mer harvest is therefore an important source of activity and income for fishermen from developing countries.

Bêche-de-mer fisheries have a long history, as the Chinese have sought sea cucumbers for a thousand years or more in India, Indonesia, and the Philippines (Conand, 1986, 1989a, 1990). During the 18th and 19th centuries, traders gathered them in a wider area. A lithograph from the d'Urville Expedition of

1839 (Fig. 2) shows a trader's shore plant in the Northern Territory of Australia, complete with boiling and smoking equipment. Conand (1986, 1989a, 1990) also described the temporal and spatial variability in the harvest of sea cucumbers. These fisheries are still poorly documented and, in many cases, may not be well managed.

In this review, recent trends in the world holothurian fisheries are analyzed for 1986–90. Regional fisheries are divided according to geographical area and the species harvested. Tropical fisheries tend to be multispecific, whereas temperate fisheries are monospecific. Tropical fisheries in the Pacific and Indian Oceans produce the dry product and are divided into four regions: Tropical South Pacific Islands, Western Central Pacific countries, Eastern Indian Ocean, and Western Indian Ocean. Temperate fisheries for fresh or frozen product are limited to the North Pacific Ocean and are subdivided into Western and Eastern Pacific regions. The description of each fishery is based on available statistics and personal observations.

The world bêche-de-mer market is largely controlled by Chinese traders, and historical data from 1917 to 1986 were reviewed by Conand (1986, 1989a, 1990). Recent statistics are presented here for the two main market centers, Hong Kong and Singapore. These markets are also the major re-exporting centers. Taiwanese statistics are analyzed here for the first time. Evaluation of the sea cucumber landings and bêche-de-mer production is presented for 1986–90. This information is useful in documenting the main characteristics of the sea cucumber fishery and prospects for its development and management.

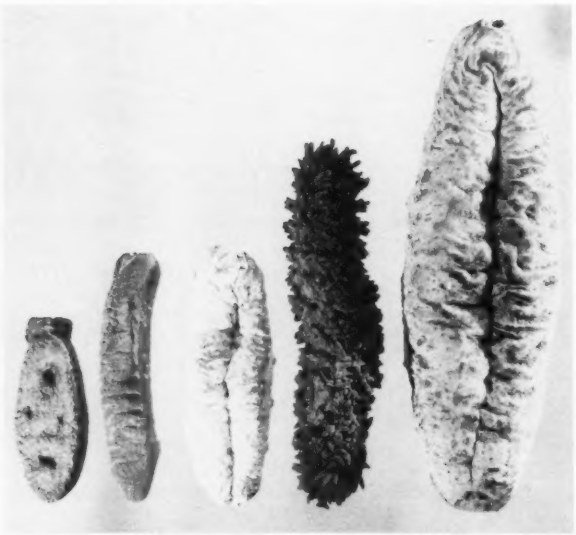

Figure 1.—Bêche-de-mer samples from several tropical holothurians: From right to left are *H. nobilis*, *T. ananas*, *H. nobilis* (lower grade), *H. scabra*, and *Actinopyga* sp. Photo by C. Conand.

Collection of Fishery and Trade Statistics

In most developing countries little official control is exercised on the artisanal sea cucumber fisheries. Consequently, relevant information and statistics are not always available. The complexity of market routes, from the fisherman to the consumer, has been shown by several studies (Sachithananthan, 1972; Conand, 1990). This makes it difficult to obtain statistics on the stages of the market, from the different sources outlined in Figure 3. Information sources include stock assessments and capture, processing, export, import, and international trade statistics.

Figure 2. — An 1830's sea cucumber processing plant in Northern Australia (from a lithograph drawn by L. LeBreton in 1839) made on the d'Urville Expedition and courtesy of the State Library of the Northern Territory of Australia, Darwin).

Stock Assessments

Exploratory scientific surveys are conducted by various countries. Scientific divers give estimates of abundance, in terms of densities or sometimes in catch per unit effort (CPUE) (Conand, 1986). The data, however, are limited by the diversity of techniques used and species surveyed. One exception is evident in the regular surveys conducted by the Washington State Department of Fisheries which document the effects of regulation on this monospecific fishery.

Capture Statistics

Little information is available on catch (live weight), catch effort (number of fishermen and harvest time), and CPUE, as fishermen generally do not use logbooks. Estimates have occasionally been made by scientists. In the State of Washington (U.S.A.), catches are recorded from fishing logs.

Processing Statistics

Holothurian catches are often bought by processors who also export bêche-de-mer. During the different stages of the processing (boiling, gutting, drying), the length and weight of the holothurians are greatly reduced, resulting in the final product weighing about 10% of the original weight and measuring 50% or less of the original length. This difference has to be taken into account when using statistics, due to inconsistencies between catches in fresh weight and the processed product.

Export Statistics

National statistics from customs agencies or fisheries departments are useful for estimating catch levels in producer countries which, for the most part, are not consumer countries.

International Trade Statistics

Analyses of Hong Kong and Singapore imports from producer countries and subsequent re-export of bêche-de-mer to consumer countries are important in understanding world trade. FAO yearbooks of fishery statistics (catches and commodities) also provide international trade data for the main countries.

Import Statistics

A comparison of national import statistics from the major consumer countries with data from international trade statistics is a source of complementary information.

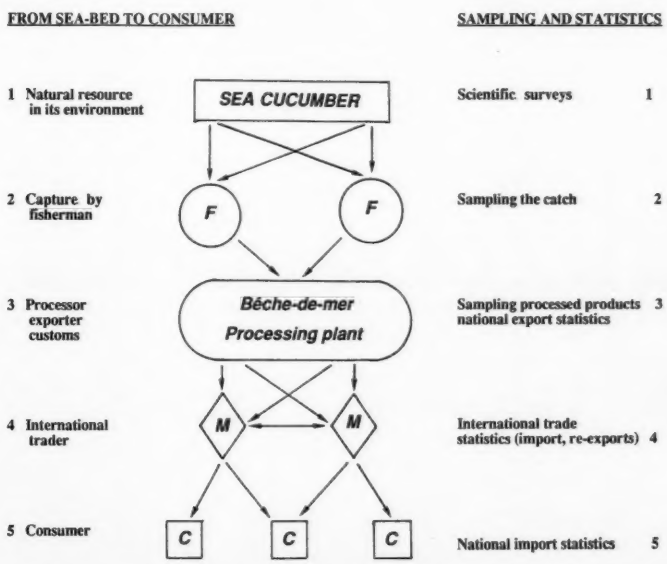

Figure 3. — The holothurian fishery, from the sea-bed to the consumer and the levels for collecting statistics.

Tropical Fisheries

Tropical fisheries are traditionally based on several holothurians (Fig. 1). The species may be classified into three categories of commercial importance based on: Abundance in shallow waters, size, thickness and quality of the body wall, and main market demand and value. The species of highest commercial value (Conand, 1986) in category one are the black teat fish, *Holothuria nobilis;* the white teat fish, *H. fuscogilva;* the sand fish, *H. scabra,* and the recently described (Conand, 1986) white sand fish, *H. scabra versicolor.* The second category (medium value) includes the brown fish, *Actinopyga echinites;* the black fish, *A. miliaris;* and the prickly red fish, *Thelenota ananas.* Finally, the third category (low commercial value) includes *H. atra, H. fuscopunctata, Stichopus chloronotus,* and *S. variegatus.*

Although no standard procedure exists, processed bêche-de-mer grading depends on three main criteria: Commercial category of the species, size of the product (in length or weight), and the quality of the processing.

Although the commercial species are Indo-Pacific in their distribution, the Indian Ocean fisheries are traditionally based on the sand fish, *H. scabra,* while the Western Pacific fisheries use several species. The reproductive biology is now well known for many species, but growth and mortality need more study (Shelley, 1985; Conand, 1989a, b). The biology of the medium-valued *Actinopyga miliaris* is unknown.

Tropical Pacific Islands

Sea cucumbers are harvested on many South Pacific islands. Fisheries data for New Caledonia, Fiji, Papua New Guinea, and the Solomon Islands were analyzed up to 1986 by Conand (1986, 1989a, 1990).

New Caledonia

The history of the sea cucumber fishery in New Caledonia, traced back to the nineteenth century, has shown wide fluctuations in connection with politi-

cal and socioeconomic events, as well as with the state of the stocks (Conand, 1986, 1989a). The recent revival of the bêche-de-mer fishery started in 1983, when New Caledonians of Chinese origin started to organize the fishing, processing, and trade. As all the catches in New Caledonia are exported, the export statistics provide accurate and easily obtainable data. Table 1 shows the fluctuations in recent annual landings, with a mean annual export of 103 metric tons (t). Annual production alternates from high years (1984, 1986, 1988, 1990) to low (1985, 1987, 1989). The overall trend, however, appears to be generally downward. The number of export companies also fluctuates. Although up to twelve different companies have exported bêche-de-mer from New Caledonia, only three of them share the major part of the market. Their respective importance also fluctuates (Fig. 4). The exports of the first company fell to 200 kg in 1990. The third company has increased in importance and now handles most of the exports of bêche-de-mer from New Caledonia, while the fourth, which started in 1990, handles 20% of the exports (Fig. 4). The major destinations were Hong Kong and Singapore. In 1987 and 1988, the tonnages exported to Singapore declined, and, since 1989, Singapore has disappeared from the statistics. In 1989 and 1990, exports were mostly destined for Hong Kong, with 3.7 t sent to Taiwan in 1990 (Fig. 4). The other sources of variability that cause annual production to fluctuate include the species collected, the fishing grounds, and the organization of fishing and processing.

About 100 fishermen are now involved in the sea cucumber fishery. Most are grouped at the tribal level or in cooperatives located primarily on the northeast coast of New Caledonia. On the west coast, a few individual fishermen sell their catch to the processors or exporters. Harvesting takes place at low tide on the reef flats (Fig. 5). Each fisherman collects sea cucumbers in a small area, filling up sacks which are then left on the reef flat until the tide is high. The catch is traditionally processed to bêche-de-mer and sold to the exporter at prices according to their grade.

There have been recent changes in the species harvested. At present, more than 75% of production is from a category-two species, the black fish, which occurs in dense populations on reef flats of the northeast coast. This species is prone to eviscerate, a behavior that results in autotomy of the internal organs and their expulsion through the anus. The catch of black fish is processed the day after harvest, by which time, most have expelled their gut. As a result, the traditional stages of slitting and gutting are not necessary (Fig. 5). Among the category-one species, the sand fish and the white sand fish are still fished in some localities, but exploitation of black teat fish and white teat fish have

Table 1. — Recent bêche-de-mer production (t) from the Tropical Pacific Islands. Sources: National statistics, Asian market imports (Hong Kong, Singapore, Taiwan), FAO statistics.

Islands and data sources	Production (t)				
	1986	1987	1988	1989	1990
New Caledonia					
National statistics	180	77	135	55	126
Asian market imports[1]	100	34	28		
FAO catch	2,520	2,240	1,350	548	
FAO exports					
Fiji					
National statistics	230	670	665	360	323
Asian market imports	155	712	1,295	251	
FAO catch	416	1,026	761	998	
FAO exports	229	640	717	365	
Papua New Guinea					
National statistics	106	192	203	195	
Asian market imports	97	152	327	226	
FAO catch					
FAO exports	85	120	229	157	

[1] Singapore only.

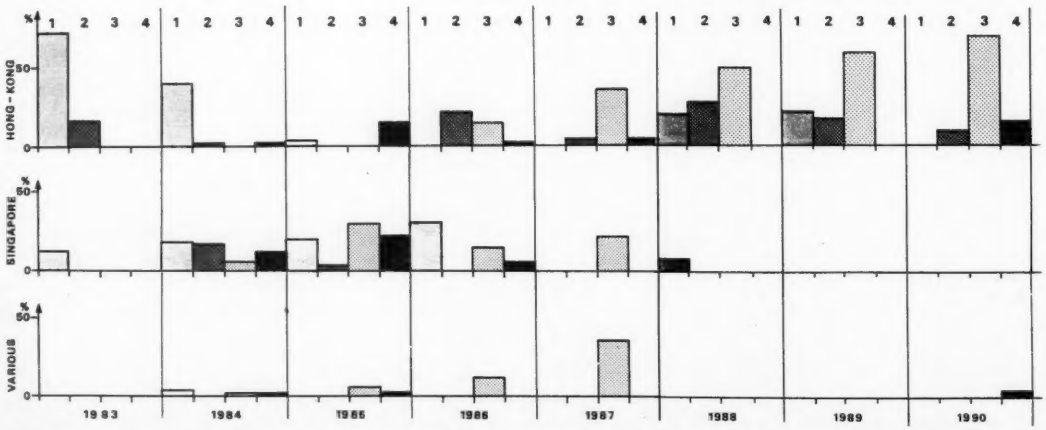

Figure 4. — Exports of bêche-de-mer from New Caledonia, in percentage of annual tonnage, by company and by destination. The numbers 1, 2, and 3 represent main companies; 4 is "other" companies.

markedly decreased. This change is probably related to the trade with The People's Republic of China which now accepts less valuable products.

Fiji

In Fiji, *H. scabra* is locally used as a foodstuff, while the bêche-de-mer fishery is traditionally multispecific. The bêche-de-mer industry has undergone a recent major expansion as shown by several sources (Table 1). From a small industry producing some 20–30 t of dried product in 1983, annual production rose to over 700 t in 1988 (Preston, 1990). The major destinations of the Fijian product are Hong Kong, Singapore, and Taiwan. Although the data varies, export statistics from the Fishery Department, import statistics from Fiji into the Asian markets, and FAO yearbook statistics on nominal catches and exports show correlations. Maximum landings were recorded in

Figure 5. — Harvesting and processing of the blackfish *A. miliaris* in New Caledonia. A) Harvesting on the reef. B) The sacks full of sea cucumbers are shipped. C) Sorting out by size. D) Boiling. E and F) Sun drying. (Photos by C. Hoffschir.)

1987 and 1988 (Table 1). In 1989–90, the sea cucumber harvests appear to have decreased. The expansion of the fishery was accompanied by several structural changes, primarily in the shift from *H. nobilis* and *H. fuscogilva* toward a less valuable species, *Actinopyga miliaris,* which now makes up 95% of Fijian exports. As noted for New Caledonia, this shift to a less valuable product is probably in response to demand for this product by the Chinese market. Another reason why *A. miliaris* can now be processed economically is the establishment of centralized processing facilities used for large batches of sea cucumbers. To prevent overfishing, which could result from this centralized processing, recent legislation bans exports of the locally consumed *H. scabra.* To protect small specimens, the minimal legal length of the processed product is now 7.6 cm. The Fijian Government is also encouraging the development of an association of licensed exporters, who will establish and maintain the quality standards for processing and provide information on the sea cucumber fishery to monitor the stocks (Preston, 1990).

Papua New Guinea

In Papua New Guinea, *H. scabra* is occasionally consumed locally, and the bêche-de-mer fishery dates back to the 18th century. After a period of unimportance from 1977 to 1985, the fishery has played an increasingly important role as an income earning activity for inhabitants of coastal communities (Conand, 1989a). This has been of local significance due to the recent depression in copra prices. Statistics from different sources are presented (Table 1). Data for 1990 are needed to determine if the bêche-de-mer fishery declined in that year, as in New Caledonia and Fiji. Unlike other Pacific Islands, in Papua New Guinea the target species in 1989 was *H. scabra.* A research program for national management of the sea cucumber resource is now being conducted by the Department of Fisheries and Marine Resources (Lokani, 1990).

Western Central Pacific Countries

Recent developments of the bêche-de-mer fisheries in The Philippines, Indonesia, and Malaysia are presented in Table 2.

The Philippines

Unfortunately, there is very little information on the sea cucumber fishery in The Philippines, although it is the second largest producer in the world, with catches of around 20,000 t per year. Three statements can be made from comparison of the statistics (Table 2): 1) the FAO export data correlate with the national statistics and the sum of the imports of the three main markets, Hong Kong being the major importer (see Table 5), 2) F.A.O. nominal catches appear overestimated, and 3) after a peak in 1987–88, exports of bêche-de-mer decreased in 1989.

Table 2. — Recent bêche-de-mer production (t) from the Western Central Pacific countries. Sources: National statistics, Asian market imports (Hong Kong, Singapore, Taiwan), FAO statistics.

Nations and data sources	Production (t)				
	1986	1987	1988	1989	1990
Philippines					
National statistics		2,195	2,062	1,032	
Asian market imports	1,662	2,014	1,815	670	1,218
FAO catch	3,367	3,612	3,193	3,534	
FAO exports	1,659	2,195	2,062	1,022	
Indonesia					
National statistics					
Production	3,670	4,605	4,755	4,888	4,679
Exports[1]	2,342	2,877	3,644	3,040	3,438
Asian market imports	2,820	2,678	3,633	1,987	
FAO catch	478	512	590	590	
FAO exports	2,362	2,517	3,480		
Malaysia					
National statistics					
Asian market imports	138	148	114	74	
FAO catch	500	800			
FAO exports	252	268	135	317	

[1] To Hong Kong, Singapore, and Taiwan.

Indonesia

Detailed bêche-de-mer export statistics from several sources have been analyzed (Table 2). Indonesia is now the major world producer and exporter of bêche-de-mer product. From the national statistics, production has been around 4,700 t/year since 1987. The catch data might be overestimated by 1,000–1,500 t, because the pooled Hong Kong, Singapore, and Taiwan imports, as well as FAO export data are always lower than data on national production.

Local consumption by people of Chinese heritage in Indonesia has not been evaluated, but it probably does not exceed a few hundred metric tons. From FAO export data, as well as from the pooled market imports, production appears to have peaked in 1988, as in other countries. In the Indonesian fishery, two types of fishing practices are undertaken according to the size of the boat.[1] With small boats, three or four fishermen harvest daily on local reefs, usually without diving equipment. The catch is processed when they return. With larger boats, around ten fishermen travel to distant reefs for periods of up to several months, often with their families. They use diving gear (compressed air) and sell the processed product in the nearby towns. Approximately ten species of sea cucumbers are processed by traditional Indonesian methods which may include two unusual features: Soaking in salt before boiling and incising the body wall of larger species. These practices give an unusual appearance to the processed product and probably result in a lower quality and less valuable product.

Malaysia

The Malaysian situation is complex, as the country appears to be simultaneously a producer, exporter, importer, and consumer. From the available statistics, the products are preferentially exported to Singapore. There is a paucity of data on the Malaysian fishery, and more information is needed to understand its organization.

[1] A. Tuwo, Laboratoire d'Océanographie biologique, UBO, Brest, France. Personal commun., 1992.

Table 3. — Recent bêche-de-mer production (t) from the Indian Ocean countries. Sources: Asian market imports (Hong Kong, Singapore, Taiwan), FAO statistics.

Nations and data sources	Production (t)				
	1986	1987	1988	1989	1990
India					
Asian market imports	67	79	33	94	
FAO catch					
FAO exports	33	56	34		
Sri Lanka					
Asian market imports	78	47	72	52	43
FAO catch					
FAO exports	54	45	61	32	
Maldives					
Asian market imports	3	19	347	367	551
FAO catch	3	33	553	553	
FAO exports	3	33	553	500	
Western Indian Ocean countries					
Asian market imports	382	535	620	470	912
FAO catch	250	315	273	227	
FAO exports	188	191	433	114	

Eastern Indian Ocean Countries

India and Sri Lanka are traditional producers in the northeastern Indian Ocean, and the Maldives are an important newcomer (Table 3). These countries do not have domestic bêche-de-mer markets.

India and Sri Lanka

In India, the industry is restricted to the Gulf of Mannar and Palk Bay, although sea cucumber resources are found in many islands. In Sri Lanka, the fishery is established in the Northern Cape. The fishery research institutes of India (Central Marine Fisheries Research Institute) and Sri Lanka (National Aquatic Research Agency) have been conducting studies on the biology of several commercial holothurians and have evaluated the resources for many years. They recently organized a bêche-de-mer workshop which brought together persons involved in the biology, fishery, and trade of commercial species (James, 1989a, b). Overfishing has been reported for both countries. This indicates that the fishery needs to be regulated by size limit on the processed products and by regulation of exports. From the recent statistics presented in Table 3, it appears that the exports are regular and <100 t/year from each country. India exports largely to Singapore, whereas destinations of the Sri Lankan product are more diverse.

The Maldives

The Maldives (Table 3) initiated bêche-de-mer production around 1986, at first with very low quantities. A huge increase has brought exports to over 300 t/year since 1988. It is desirable to gain information on this recently expanding fishery to prevent overfishing.

Western Indian Ocean Countries

Along the western coasts of the Indian Ocean, many African and Arabic countries produce bêche-de-mer. The Republic of South Africa, Mozambique, Tanzania, Kenya, Yemen, United Arab Emirates, and Madagascar all export on a regular basis. The data for these countries have been summarized (Table 3) to give an overview of the regional fisheries. When the total imports by Hong Kong, Singapore, and Taiwan is considered, the data show peaks in 1988 and 1990. This value is always higher than FAO data. Singapore appears to have been the major destination for bêche-de-mer produced in this region until 1989. Other countries, including Sudan and Mauritius, which produce smaller quantities of bêche-de-mer, occasionally appear in the statistics. Comparative examination of the producers in this region shows that Tanzania was the dominant producer until 1989, exporting around 200 t/year. When combined, Kenya and Madagascar exported over 300 t in 1990. The other countries exported around 50 t/year each, or less until 1989, with an increase of their exports in 1990.

Temperate Fisheries

Temperate fisheries are divided into the Western and Eastern Pacific regions. The Western Pacific region includes the Japanese and Korean fisheries, which are largely for fresh product, and the smaller Russian and New Zealand bêche-de-mer fisheries. In the Eastern Pacific, the start of small but growing fisheries in Canada and the United States was described by Sloan (1985, 1986). This fishery is for fresh-frozen and bêche-de-mer product. These temperate fisheries are more or less monospecific, based essentially on *Stichopus japonicus* in the Western Pacific and on *Parastichopus californicus* in the Eastern Pacific.

Western Pacific Ocean

The Japanese and Korean fisheries are mostly for fresh product and have been summarized up to 1983 (Conand, 1990). Recent information is based on FAO data, as most of the national literature is published in Japanese. Figure 6 shows a slight, but consistent decrease in landings from 1983 to 1989.

Japanese fisheries, although widely distributed along the coasts, are particularly important in Hokkaido. A small part of the catch is processed as bêche-de-mer, as illustrated in the recent Japanese best-seller "The eyes of the sea cucumber" (Tsurumi, 1990). Mariculture of *Stichopus japonicus* has started in Hokkaido and involves hatchery pro-

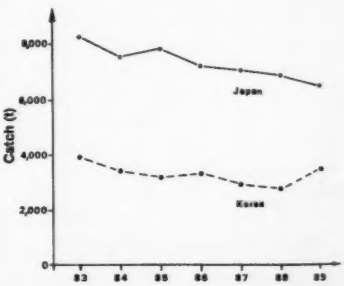

Figure 6. — Catches of *Stichopus japonicus* in Japan and Korea (from FAO data).

duction of juveniles which are transplanted to fishing grounds From the 1990 statistics, Japanese imports of holothurians are low, with frozen products at 115 t and dried products at 18 t.

The Russian fishery in Peter The Great Bay has declined in recent times, probably due to pollution, but maricultural research continues.[2]

New Zealand's interest in a potential fishery for *Stichopus mollis* has recently increased. The fishery started in 1990 with a special permit granted to one company to collect *S. mollis* from the southwestern fjords. The permit was linked to the collection of information in collaboration with marine scientists to assess the viability and impact of the fishery (Mladenov and Gerring, 1991). The ecology and reproductive biology of *S. mollis* has been documented (Sewell, 1990; Sewell and Bergquist, 1990).

Eastern Pacific Ocean

A small fishery for *Parastichopus californicus,* utilizing scuba, started around 1970 in the State of Washington. Since that time, catches of this species have been reported from British Columbia (Can.) and the State of California (U.S.A.). In California, a smaller species, *P. parvimensis,* also forms part of the catch (Sloan, 1985; 1986). The Washington and the Canadian fisheries have a unique feature in that the five longitudinal muscles are stripped from the body wall and frozen for export to Japan and Taiwan. The body wall is then processed into bêche-de-mer for export. Sloan's (1985, 1986) reviews stated that the fishery is characterized by incomplete market development which imparts instability and causes non-stock-related fluctuations in landings.

Several recent studies have contributed to our knowledge of the biology of *P. californicus*, including studies of its reproductive cycle and spawning behavior (Cameron and Fankboner, 1986; McEuen, 1988; Smiley, 1988a). There are also studies detailing ovulation, the maturation hormone, and metamorphosis of this species (Smiley and Cloney, 1985; Smiley, 1986, 1988a, b). Recently, Cameron and Fankboner (1989) described the development, recruitment and juvenile ecology of *P. californicus,* aspects of which are poorly documented for other sea cucumbers.

The Washington dive fishery is controlled by the Department of Fisheries (Bradbury, 1990; Bradbury[3]). Up to 1987, the fishery was assessed through mandatory logbooks filled out by licensed divers, and there were no seasonal or harvest area restrictions. Following signs of overfishing, the Washington Department of Fisheries divided state waters into four harvest areas: The San Juan Islands, Strait of Juan de Fuca, Central Puget Sound, and South Puget Sound/Hood Canal. Commercial exploitation of these areas now rotates, so each district goes unfished for $3\frac{1}{2}$ years after a 6-month harvest. A seasonal restriction has also been imposed, with fishing allowed for 6 months a year, from 1 May to 31 October. The period for closure was decided with respect to the seasonal atrophy of the viscera of *P. californicus* described by Fankboner and Cameron (1985). This rotation of harvest areas should allow the sea cucumbers to spawn at least once before being harvested. Recent research on the biology of this species provides a scientific basis for the management of the fishery. Limited-entry legislation was also approved in 1990, and the number of boats licensed has declined.

Figure 7 shows the data for the Eastern Pacific fishery from 1975 to 1990. These landings figures, however, should be viewed cautiously, as some catches may have gone unreported. Up to 1977 the sea cucumber landings remained under 10 t/year and then fluctuated for 10 years at an intermediate level under 200 t/year. A marked increase is shown for the last three years with a record catch in 1989 of over 1,000 t. Table 4 summarizes the parameters of the fishery. The value per kilogram increased 2.5-fold during the years 1986–90, making the fishery attractive for divers. Since 1983, the number of boats and effort, in dive hours, increased until the 1990 legislation on limited entry. The number of buyers also increased. The CPUE, in number of sea cucumbers, although variable, is decreasing in the different districts, and, simultaneously, the divers are harvesting in deeper waters.

Among the different measures taken to prevent overfishing, the limited-entry legislation is probably the most important conservation strategy. In the meantime, assessments of the residual resource left behind after fishing and of the recovery rate of holothurian populations are being conducted by fishery biologists. At present, the Washington

[2]T. Naidenko, Institute of Marine Biology, U.S.S.R. Academy of Sciences, Vladivostok. Personal commun., 1992.

[3]A. Bradbury, Washington Department of Fisheries, Brinnon, Wash. Personal commun., 1992.

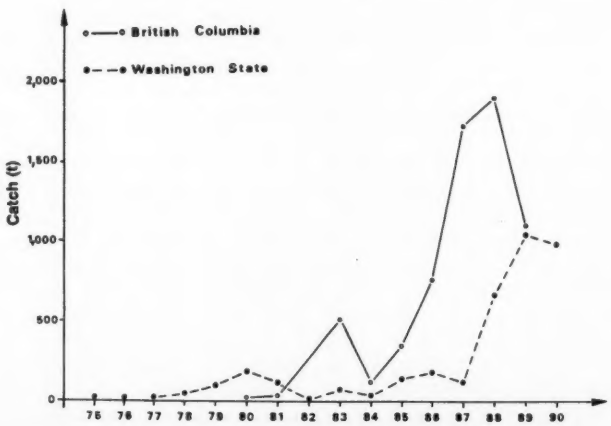

Figure 7. — Catches of *Parastichopus californicus* in Washington and British Columbia.

dive-fishery is the best documented and the most carefully managed sea cucumber fishery in the world.

The sea cucumber landing statistics from California[4] are as follows: 1984, 24 t; 1985, 33 t; 1986, 35 t; 1987, 49 t; 1988, 72 t; 1989, 72 t; 1990, 6 t. Landings consistently stayed under 100 t and, after a relative peak in 1988–89, appear to be declining.

The fishery in British Columbia exhibited rapid development since Sloan's (1986) review. Landings statistics[5] (Fig. 7) show a maximum approaching 2,000 t in 1988. The subsequent decline in 1989 is based on preliminary data.

Main Markets

Hong Kong Market

Hong Kong is by far the world's major bêche-de-mer market. Table 5 and Figure 8 show tonnages, total value in Hong Kong dollars, and the average price per kilogram. The US$ equivalent was calculated from exchange rates given in FAO (1991). For the most important countries, the statistics are expressed as percentage of annual tonnage and value of product supplied to Hong Kong.

The historical record for tonnage imported to Hong Kong was 7,700 t in 1988, followed by a drop in 1989. The record value for imports was in 1990 at HK$231,500 (equivalent to US$29,326), and the mean price per kg is increasing. Hong Kong imports bêche-de-mer largely from ten countries, listed here in decreasing order of importance as of 1989: Indonesia, Singapore, The Philippines, Fiji, People's Republic of China, Maldives, Solomon Islands, Papua New Guinea, Madagascar, and New Caledonia. The mean price per kilogram is low for the products imported from The Philippines and Indonesia and is slightly higher for the Pacific Islands. Products coming from the Western Indian Ocean (Madagascar, Tanzania, Mozambique) fetch good prices. Prices are highest for the temperate Pacific countries (United States and Canada).

Re-exports peaked in 1987 with nearly 5,000 t of bêche-de-mer leaving Hong Kong for other markets. During the last few years, the average price has

[4]W. Klawe, IATTC, Scripps Institution of Oceanography, La Jolla, Calif. Personal commun., 1991.

[5]A. Campbell, Fisheries and Oceans, Canada, Pacific Biological Station, Nanaimo, B.C. Personal commun., 1991.

Table 4. — The dive fishery for sea cucumber in Washington.[1]

					District 1			District 2			District 3			District 4		
						CPUE[4]			CPUE[4]			CPUE[4]			CPUE[4]	
Year	Catch (t)	Value[2] (US$10[6])	Price (US$)	Boats[3]	E[5]	N	kg	E[5]	N	kg	E[5]	N	kg	E[5]	N	kg
1983	170			9				99	530		281	275				
1984	39			14	68	271	80	225	495		310	220		28	502	
1985	146			15	74	232	69	162	397		1,763	272		336	636	
1986	181			16	345	200	59	253	425		1,116	249		237	321	
1987[6]	127	0.89	0.70	25	837	248	73									
1988	871	1.07	1.23	78				6,462	381	106						
1989	1,146	1.87	1.63	125							11,437	239	66			
1990	992	1.75	1.76	79										5,833	264	73
1991	1,243	3.79	2.03	70	10,341		120									

[1] Bradbury (text footnote 3).
[2] Estimated from the average price paid per bucket of slit, drained sea cucumbers.
[3] Number of boats making at least one landing.
[4] Mean number (N) or weight in kg per dive hour from harvest log.
[5] Total dive hours.
[6] Since 1987, area openings are rotating by district.

Table 5. — Sea cucumber imports and re-exports from the Hong Kong market.

				Imports by main country of origin[1]											
				Philippines			Indonesia			Pacific Islands			Singapore		
Year	Tonnage[2]	Value[3]	Price[4]	%T	%V	P	%T	%V	P	%T	%V	P	%T	%V	P
1986	5,193	110,947	21.3	30	19	13.5	47	31	13.8	7	11	36.1	6	11	39.7
1987	5,896	131,820	22.3	33	16	10.9	37	28	17.1	13	14	24.4	6	13	44.4
1988	7,716	191,240	24.8	22	13	14.2	40	31	19.0	18	19	26.0	10	14	33.5
1989	4,526	134,306	29.7	14	8	16.3	39	29	21.7	9	9	27.6	23	20	25.4
1990	6,596	231,467	35.1	18	10	19.9	32	27	29.3	9	13	50.0	20	17	29.3
				Re-exports by main country of destination[1]											
				China			U.S.A.			Taiwan			Singapore		
				%T	%V	P	%T	%V	P	%T	%V	P	%T	%V	P
1986	4,535	59,822	13.2	86	54	8.2	1	10	84.0	6	16	31.9	3	14	56.2
1987	4,975	55,479	11.2	87	52	6.7	1	8	96.9	8	20	26.6	2	13	71.5
1988	3,303	56,322	17.0	79	45	9.6	1	9	119.5				4	14	66.3
1989	1,847	46,723	25.3	74	46	15.7	3	15	60.6				3	7	60.6

[1] T=tonnage, V=value, P=price per kilogram.
[2] In metric tons.
[3] In 1,000. 1 HK$ equivalent in US$ for 1986 is 0.1284; 1987, 0.1284; 1988, 0.1281; 1989, 0.1282; 1990, 0.1267. Exchange rates from FAO (1991).
[4] Price per kilogram in HK$.

been lower for re-exports. This is due to cheaper products destined for the People's Republic of China, which represents 75% of the re-exports.

Singapore Market

Singapore is the second largest market for imports and re-exports, but the local retail market is also very important. The available statistics for the past few years are analyzed and the results are recorded in Table 6 and Figure 9. As noted by Van Eys and Philipson (1991), the import statistics are unreliable because bêche-de-mer does not carry an import duty and is therefore not always specifically identified in shipments of dried seafood. This explains why in 1986 the re-export statistics exceeded the import statistics. For the last few years, however, the figures appear to be more accurate. Because there is no local production, domestic consumption can be estimated from the difference between imports and re-exports. Local consumption increased from 22 t in 1987 to 69 t in 1988 and 105 t in 1989. It decreased to 42 t in 1990. Compared with Hong Kong, there has been only a slight, more or less regular, increase in the tonnages imported, which as for Hong Kong, peaked in 1988. On the whole, for the recent period, Hong Kong handled six times more bêche-de-mer than Singapore. At present, the major suppliers to the Singapore market are the Maldive Islands, Pacific Islands, Tanzania, and Malaysia. Until recently, the main suppliers were Sri Lanka, India, and The Philippines. Re-export destinations have also changed. More than half of the re-export tonnages are now destined for Hong Kong. Based on the mean values per kilogram, high-grade bêche-de-mer goes preferentially to Taiwan, and the low-grade product goes to Malaysia.

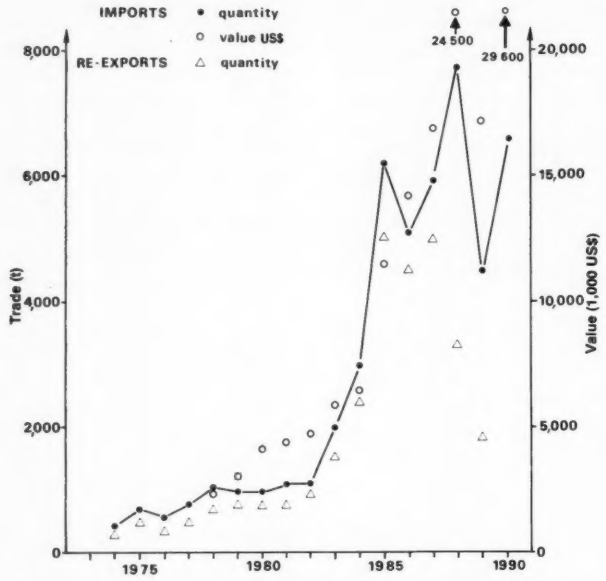

Figure 8. — Hong Kong trade statistics for bêche-de-mer (1973–90). Values in US$ are calculated from exchange rates given in Table 5.

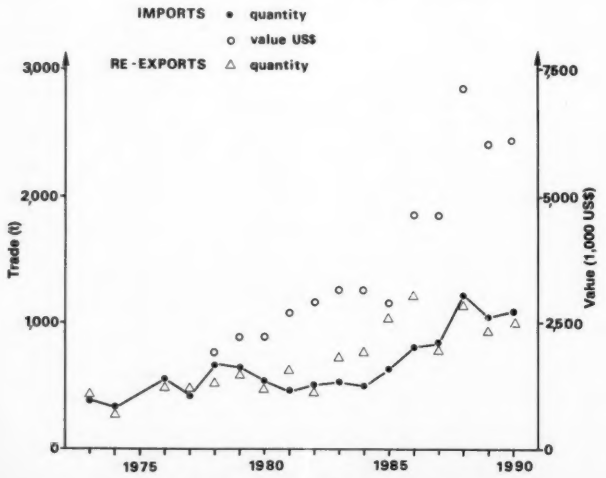

Figure 9 — Singapore trade statistics for bêche-de-mer (1973–90). Values in US$ are calculated from exchange rates given in Table 6.

Trade Between Hong Kong and Singapore

Trade between Hong Kong and Singapore was obtained from their respective import and re-export statistics (Table 7). If there were good agreement between the statistics, imports from Singapore should be equal to re-export to Hong Kong, and imports from Hong Kong should be equal to re-exports to Singapore. Comparison of the data, however, shows that while the order of magnitude is the same, the figures do differ. Hong Kong's import and re-export tonnages are higher than the corresponding re-exports and imports from Singapore. On the whole, the general tendency is a flux from Singapore to Hong Kong which is opposite to the flux which existed between 1981 and 1984 (Conand, 1986). The exchange is made through sister companies, with higher grades of bêche-de-mer being imported by Singapore and lower grades by Hong Kong, probably because Hong Kong supplies the Chinese market with lower grade product.

Table 6. — Sea cucumber imports and re-exports from the Singapore market.

				Imports by main country of origin[1]											
				Malaysia			Tanzania			Pacific Islands			Maldives		
Year	Tonnage[2]	Value[3]	Price[4]	%T	%V	P	%T	%V	P	%T	%V	P	%T	%V	P
1986	814	9,599	11.8	17	10	6.7	14	6	5.1	23	24	12.1	0.4	0.5	15.6
1987	840	9,251	11.0	17	12	7.8	24	12	5.5	16	17	11.3	2	3	15.5
1988	1,225	14,614	11.9	8	4	5.9	21	15	8.6	14	12	10.0	28	34	14.5
1989	1,023	11,863	11.4	7	3	5.1	16	11	7.8	23	17	14.4	25	22	10.8
1990	1,068	12,321	11.5	6	3	5.3	10	5	6.8	15	17	13.4	29	25	9.9
				Re-exports by main country of destination[1]											
				Hong Kong			Malaysia			Taiwan					
				%T	%V	P	%T	%V	P	%T	%V	P			
1986	1,217	6,683	5.5	54	47	4.8	35	33	5.1	9	16.9	9.4			
1987	818	7,395	9.0	47	55	10.5	36	27	6.8	14	13	8.6			
1988	1,156	11,232	9.7	54	62	11.1	34	20	5.8	7	13	16.0			
1989	938	10,043	10.7	46	46	10.6	27	14	5.7	16	29	18.5			
1990	1,026	11,022	10.7	63	56	9.6	15	9	6.7	12	21	18.9			

[1] T=tonnage, V=value, P=price per kilogram.
[2] In metric tons.
[3] In 1,000. 1 S$ equivalent in US$ for 1986 is 0.4593; 1987, 0.4751; 1988, 0.4970; 1989, 0.4990; and 1990, 0.5072. Exchange rates from FAO (1991).
[4] Price per kilogram in S$.

Other Markets

Taiwan, like other major importers (The People's Republic of China, Malaysia, Thailand), was once considered to depend on re-exports from Singapore and Hong Kong (Sachithananthan, 1972). This paper is the first detailed analysis of Taiwanese imports. It gives precise information, since 1983, on tonnages, values, and countries of origin (Table 8). From the 8 years analyzed, it appears that in 1987 and 1988, imports doubled compared with the mean for this period. The decrease in imports in 1989 and 1990 is compensated for by the increase in mean value per kilogram. Up to 1985, the origin of the product was essentially Indonesia. Imports are now more diverse with supplies coming from Singapore and Japan. Very high quality products are supplied by Japan. The Pacific Islands (New Caledonia, Fiji, Papua New Guinea) and Indian Ocean countries (Mozambique, Sri Lanka) show variable contributions. Unlike Hong Kong and Singapore, there are no re-exports from Taiwan, because all imports of bêche-de-mer are consumed locally.

Table 7. — Exchanges of bêche-de-mer between Hong Kong and Singapore (1986–90).

Item and unit	1986	1987	1988	1989	1990
Hong Kong					
Imports from Singapore					
T[1]	301	399	798	1,068	1,313
V[2]	11,938	17,719	26,710	27,138	38,447
P[3]	39.7	44.4	33.5	25.4	29.3
Re-exports to Singapore					
T[1]	153	103	123	55	
V[2]	8,551	7,364	8,157	3,334	
P[3]	56.2	71.5	66.3	60.6	
Singapore					
Imports from Hong Kong					
T[1]	84	30	48	18	47
V[4]	1,744	542	847	301	1,060
P[5]	20.8	18.1	17.6	16.7	22.6
Re-exports to Hong Kong					
T[1]	656	386	631	439	651
V[4]	3,157	4,068	6,977	4,660	6,221
P[5]	4.8	10.5	11.1	10.6	9.6

[1] Tonnage.
[2] Value in 1,000 HK$.
[3] Price/kg in HK$.
[4] Value in 1,000 S$.
[5] Price/kg in S$.

Discussion

General Trends

Although the statistics are incomplete, a tentative evaluation of the bêche-de-mer production in the Indo-Pacific and of the temperate fisheries landing is presented in Table 9. When data from different sources were discordant, national statistics were given preference. Between FAO statistics on catches, imports, and exports, and the main market statistics, the most representative data were chosen based on personal knowledge of the fishery.

Recently, bêche-de-mer fisheries have increased markedly in tropical countries. This increase was marked by two phases: In 1985–86, production increased threefold over previous activity, and during 1987–89 it doubled again. A slight decline in 1989 was recorded by many national fisheries. This decline would have been more dramatic if the Indonesian landings were not overestimated, as evident from the market data.

Indonesia and The Philippines continue to dominate the world market in terms of tonnage produced. The recent increase in production by the Eastern Indian Ocean fishery is due to the Maldives fishery which as yet is poorly documented with regard to the species harvested, the processing methods, and the trade. The increase in world production since 1985 was stimulated by an increase in demand from the People's Republic of China for a less expensive,

Table 8. — Taiwan's sea cucumber imports, 1983–90.

				Imports by main country of origin[1]								
				Indonesia			Singapore			Japan		
Year	Tonnage[2]	Value[3]	Price[4]	%T	%V	P	%T	%V	P	%T	%V	P
1983	411	1,350	3.28	90	86	3.13	1	1	3.76			
1984	345	1,425	4.13	96	93	4.03						
1985	423	1,772	4.18	92	89	4.02	1	1	6.75	3	5	5.86
1986	429	1,479	3.44	81	79	3.38	2	1	2.84		1	18.87
1987	787	3,452	4.38	64	49	3.38				4	26	25.07
1988	877	4,663	5.31	57	42	3.97	2	2	4.46	6	30	26.00
1989	357	2,965	8.30	56	35	5.17	10	8	6.23	11	42	30.21
1990	356	3,023	8.49	40	22	4.78	20	18	7.66	12	40	26.92

[1] T=tonnage, V=value, P=price per kilogram.
[2] In metric tons.
[3] In US$.
[4] Price per kilogram in US$.

Table 9. — World sea cucumber catch from the main regions, 1983–89.

	Catch (t)						
Fisheries and regions	1983	1984	1985	1986	1987	1988	1989
Tropical fisheries							
Dry weight (t)	1,445	1,414	5,400	4,000	8,000	8,200	7,800[2]
Catches (t)[1]	14,450	14,140	54,000	40,000	80,000	82,000	78,000[2]
Percentages by:							
Tropical Pacific	4	22	6	20	29	22	9
Western Central Pacific	76	66	84	67	62	66	77[2]
Eastern Indian	10	7	1	3	1	5	8
Western Indian	8	5	9	10	8	7	6
Temperate fisheries							
Catches (t)	12,958	12,215	11,558	11,653	11,903	12,468	11,922
Percentages by:							
Western Pacific	95	91	95	92	84	78	81
Eastern Pacific	5	9	5	8	16	22	19
World catches[3]	27,408	26,355	65,559	51,653	91,903	94,468	89,922[2]

[1] Data increased by one order of magnitude to account for the processing weight loss.
[2] Data might be overestimated for Indonesian catches.
[3] Tropical + Temperate catches.

lower grade product. This resulted in a rapid change in the holothurian species being exploited, from first-category species (i.e. *H. nobilis* and *H. fuscogilva*), to a second-category species, *A. miliaris*. Temperate fisheries have been more consistent, with landings of around 12,000 t/year. The slight recent decrease in the Western Pacific fishery was compensated for by the development of the Eastern Pacific fishery.

Statistics

Access to the statistics at the various levels shown in Figure 3 and their reliability is considered in order to present some conclusions and recommendations for further assessment and management of holothurian resources. Stock assessment is relatively easy for these sedentary animals, and it needs to be carried out by a combination of methods such as direct underwater counts, counts from photographs of quadrats, and remote sensing of shallow-water reefs. As described for New Caledonia, these methods are useful in assessing the biomass of the main commercial species in reef environments (Conand, 1979).

Stock assessments are rarely undertaken, and those that are available do not provide the environmental parameters required for interpretation. Catch and particularly effort data are seldom collected in tropical sea cucumber fisheries. The available statistics only provide a gross evaluation, as there are many sources of variation depending on the species, the fishing areas, and the aptitude of the fishermen. Although the statistics are of questionable quality, they show that depletion of fishing grounds due to overfishing can occur rapidly for these slow-moving animals, as shown in New Caledonia by the decreased CPUE for *H. scabra versicolor* and *H. scabra* (Conand, 1989a). Adequate capture and processing statistics are needed to establish surplus production models and should be standardized using either logbooks or assessment at the landing sites or in processing plants.

National customs agency statistics are very useful to estimate local fisheries. In this review, national export statistics are considered to represent production, and national import data are considered to represent consumption. This implies that producer countries are not consumers and that consumers are not producers. This first bias and other inaccuracies result from various customs legislation on imports and exports. Considering the present increase in bêche-de-mer fisheries, data which need to be collected include detailed records for the different species harvested and grades produced. The validity of the information should be tested through a consultation between the fisheries agencies and customs departments of each country.

World market statistics (Hong Kong, Singapore, Taiwan), as well as international FAO statistics, are very useful in checking and complementing the available national data. Their reliability to indicate national production is nevertheless reduced due to the reciprocal exchange of product between the markets. Some products are first imported by one market, then re-exported to another one, before arriving in the consumer country, as shown for Hong Kong and Singapore.

The South Pacific Commission[6] has recently started the *Bêche-de-mer Information Bulletin*, which is a useful source of information on the state of the fisheries, the markets, resource surveys,

[6] SPC, B.P. D5, Nouméa, New Caledonia.

and recent research on the biology of commercial species.

Management Recommendations

Recent trends in bêche-de-mer fisheries show a marked increase in landings due to a strong increase in demand. The risk of overexploitation at present is high. Predicting yields, an important objective of fishery research, is obtained by structural and heuristic models. Structural models need the input of data, both from the populations parameter and from the fisheries. Recent research on the reproductive biology of the majority of the commercial species allows recommendations to be made on size regulations for the fresh, or processed, product based on size at first sexual maturity (Conand, 1989a). This information needs to be utilized for fishery management. Information on recruitment, growth, and mortality of holothurians is only available for a few species (Shelley, 1985; Conand, 1989b), and research on these subjects should be given priority. Structural and heuristic models are considered to play complementary roles. As noted by Fogarty (1989), it is often possible to provide more accurate predictions with heuristic models. Fogarty (1989) also gives a number of examples where landings of mollusks and crustaceans have been related to explanatory (environmental) variables.

The case of sea cucumber fisheries shows a very complex system of interactions, where economic and social factors play important roles. To quantify the different trade pathways, price analyses have to be conducted at the national level and for the world markets in Hong Kong, Singapore, and Taiwan.

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A Cooperative Management Solution to a Fishery Commons

JEFFREY POMPE and CHARLES E. ROCKWOOD

Introduction

It is an economic truism that a scarcity of resources necessitates choice. A successful market system allocates resources in an impartial manner, auctioning them off to their highest valued uses. However, market failures do occur and common property resources, such as fisheries, are well-known examples. Unlimited access to a common property fishery negates any incentive to conserve the resource, and a classic case of overfishing is the usual result. This paper examines a shared resource, Florida's Atlantic calico scallop, *Argopecten gibbus*, which appears to have been exempt from this overexploitation and inefficiency due to a cooperative management solution.

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ABSTRACT—A common property resource with open access, such as a fishery, will be used to excess when faced with sufficient demand. This will lead to an excessive amount of effort on the part of the fishery, resulting in a depletion of the stock. This paper discusses the development of a property rights regime for the Atlantic calico scallop, Argopecten gibbus, *fishery of Florida. The management solution of the Calico Scallop Conservation Association (CSCA) provides an example of the assignment of property rights to a common property resource without resorting to governmental intervention. In this particular fishery, self-regulation limited early harvesting which would be uneconomic; there may be other fisheries in which self-regulation could be economically efficient and biologically appropriate. While this solution may not be applicable to all common property resources, for those cases which may be similar, the example of the CSCA provides valuable information that may be helpful in establishing a more efficient use of the resource. Some types of government facilitation may also be useful.*

Background

The Brevard County calico scallop fishery, along the eastern coast of Florida, was once among the largest scallop fisheries in the world. Recorded landings exceeded 40 million pounds of scallop meat in 1984. At present, the fishery is mostly inactive as a result of a biological kill caused by the protozoan parasite *Marteilia* previously unknown in this part of the Atlantic, and the appearance of which is not believed to have been associated with harvesting levels or techniques (Moyer et al[1]).

The Brevard County calico scallop fishery was developed in the early 1980's, although some commercial fishing began as early as 1967. The development was triggered by an increase in stocks and the refinement of automated steam processing equipment (Blake and Moyer, 1991). Calico scallops are fairly small, generally reaching 40–60 mm (1.6–2.4 inches) in shell height (SAFMC and GFMC, 1982). Depending on the time of year, harvesting intensity, and other factors, it requires an average of 100–350 calico scallops to yield a single pound of scallop meats and 8.75 pounds to equal 1 gallon. Not surprisingly, therefore, a viable commercial fishery had to await the development of a highly mechanized method of harvesting and processing. Not surprisingly, also, the highly mechanized methods developed have produced an economic environment in which the efficient processor is relatively large. As a result, the processing of the scallop is oligopsonistic in nature, with the 5 firms owning and operating some vessels but also sometimes contracting with private vessels. In 1988, 5 firms were active in the Brevard County calico scallop fishery, with 4 firms processing the scallops in Cape Canaveral (Rockwood and Pompe[2]).

The Brevard County calico scallop fishery was unique in the way the product was handled. Boats were normally only out about 12 hours, including runtime from the dock. (Shrimp boats, for example, may be out 3 weeks or more and may or may not freeze their product while at sea.) Calico scallops were processed mechanically as soon as they arrived in port by one of the four large processing plants located in Port Canaveral. Indeed, vessels typically were given appointment times at the plant to ensure that their product would be expeditiously handled when it arrived (Rockwood and Pompe[2]).

Although calico scallops are found in places other than the eastern United States, and even there extend as far north as North Carolina, the heaviest concentrations have been found in offshore beds, of up to 20 miles wide, from St. Augustine nearly to Fort Pierce.

Location of the processing plants in Port Canaveral was due to geography rather than mere happenstance. Calico

[1]Moyer, M. A., N. J. Blake, and W. S. Arnold. 1992. An ascetosporan disease causing mass mortality in the Atlantic calico scallop, *Argopecten gibbus* (Linnaeus, 1758). Univ. S. Fla., Dep. Mar. Sci., St. Petersburg. Unpubl. Final Rep. under grant NA90AAHSK119, April 1992, 18 p.

[2]Rockwood, C. E., and J. Pompe. 1988. Economic impact of the Brevard County calico scallop fishery. Econ. Consultants, Inc., 2423 Winthrop Rd., Tallahassee, FL 32312. Unpubl. rep., 31 p.

scallops cannot be landed just anywhere; vessel run-time to and from the scallop beds is critical to the economic viability of the fishery and to the freshness of the landed product.

The oligopsonistic nature of this fishery provided the opportunity for cooperative behavior, which was effected through formation of a Calico Scallop Conservation Association (CSCA)[3] in 1986 (Rockwood and Pompe[2]). Florida's calico scallop industry may not fit the classic model of a commons fishery, since some biologists do not consider overfishing to be a problem during most years since stocks are annual (Blake and Moyer, 1991). However, early harvesting of scallops before maturation, which could stress the fishery and prove uneconomic, was regulated by the association. Indeed, the stated purpose of the association was to hire a biologist to determine harvesting guidelines. Members agreed to limit fishing until at least 75% of the stock at a particular location reached a shell height of at least 38 mm (Blake and Moyer, 1991). Therefore, although this fishery may not fit the classic overfishing model it is still relevant to policy. The enforcement of the self-regulation will be discussed below.

Also important, the calico scallop fishery is for all intents and purposes entirely a commercial fishery. Thus, unlike so many fisheries, recreational fishermen do not compete in any serious way either for the calico scallop resource directly, or for resources which are in any meaningful sense in the same food chain. This characteristic, combined with reasonable costs of contracting, facilitated the cooperative solution.

The Commons Tragedy and Alternative Solutions

The lack of property rights to a commons area leads to social welfare losses resulting in what Hardin (1968) described as the "tragedy of the commons." This classic article explains how a herdsman is compelled to increase his herd without limit until the village commons is overgrazed. This action is "rational" for the individual, since the additional benefits for the individual herdsman exceed the additional private costs. However, the additional cost to society is greater than the additional benefit, for the eventual result is destruction of the commons. Similarly, an individual would have no incentive to protect scallop resources unilaterally if any benefits from conservation were to be shared by all members of the "commons," while the lost revenues were suffered only by those who conserve.

As Ciriacy-Wantrup and Bishop (1965) have noted, this is more accurately the case where there is open access to a natural resource. The fact that the resource is common property does not dictate a "tragedy." Therefore, it is important to differentiate between open access (res nullius), where resources can be exploited without restrictions, and common property (res communes) which can have restrictions on use.

Hanna (1990) discusses the positive attributes of community control, contending that overuse of resources is possible under private ownership as well. With open access to a resource, if sufficient demand exists, the resource tends to be overused. With a lack of enforceable property rights, scarcity rents will be dissipated, and firms will tend to overuse the resource. The current generation suffers a loss of welfare as high capital costs and inefficiency, in the form of an excess amount of boats, fishermen, and effort, results. In addition, as fish populations decline from overfishing, benefits to future fishermen and consumers may be lost or reduced.

However, if these rents can be captured by firms sharing the commons, the members have an incentive to come to a voluntary agreement that prevents overuse. Resource owners recognize that the resource has an asset value as well as a use value. By conserving the resource for future users, owners can expect a return on their investment in the form of economic profits. To maintain a commons without ruination, users must be able to exclude interlopers and regulate member-use of the resource at reasonable cost. As discussed further in the next section, the CSCA has been able to meet both conditions.

Arguments have been made that the solution to the problem of open access must be either privatization or government intervention (Hardin and Baden, 1977). However, Berkes et al. (1989) offer several examples of controlled use of a commons without resorting to one of these two possible solutions. Maine lobsters, for example, have been maintained by traditional fishing rights, enforced by the community, using violence if necessary (Acheson, 1988). The Nijukiine Forest on the lower slopes of Mount Kenya was successfully operated as a communal forest by kinship and neighborhood groups until colonial rule broke down traditional rules (Castro, 1991). Aquaculture, which provides property rights, has also mitigated the commons tragedy in some species such as crawfish, mussels, and oysters.

Privatization, the process of defining and enforcing ownership rights for individual or corporate control, may be a possible alternative to help manage some resources better. Property rights to fishing sites on rivers and streams in Scotland and England have been in operation since the 1960's (Anderson, 1983). Landowners maintain desirable fishing spots to rent to sporting groups.

Although different laws do not usually allow the same procedure in the United States, there are some similar developments. In Montana's Yellowstone River Valley, for example, some spring creeks, flowing entirely on private property, are maintained and rented by landowners (Anderson, 1983). In these cases, where rights can be established and enforced, efficient use of the streams is encouraged.

Among the various policies attempted by the government to prevent fishery overuse are regulated inefficiency, tax systems, and quotas. Unfortunately, the fisheries literature is replete with the failures of such regulation with few encouraging results. As is illustrated by the regulatory attempts of the Pacific salmon fishery, government intervention is often ineffectual and costly. Crutchfield and Pontecorvo (1969) estimated that the excessive amount of capital and labor used as a result of regulated inefficiency led to a waste of $50 million each year. In ex-

[3]Mention of trade names or commercial firms or organizations does not imply endorsement by the National Marine Fisheries Service, NOAA.

amining the regulated Pacific halibut industry, Crutchfield (1969) estimated that two-thirds of the fishing effort was unnecessary.

In addition, well meant government intentions are often negated by special-interest and rent-seeking behaviors. For example, the 1976 Magnuson Fishery Conservation and Management Act, extended the nation's oceans jurisdiction of from 3 to 200 miles, with the goal of controlling overfishing by foreign fleets. However, as foreign fishing declined, the regional regulatory body was pressed to allow increased domestic harvests. As a result, catch quotas and trip limits, meant to prevent overfishing, were lifted in 1982. With improved technology, such as fish finders, and increased demand for fish pushing up prices, certain New England fisheries, for a short time, saw an increase in catch levels. Since 1983, however, there has been a sharp drop in fish caught, due to severe overfishing (Ingrassia, 1991). Estimates quoted in Tregarthen (1992) have placed the lost value to society of the overfishing of New England waters at about $150 million per year.

The CSCA Solution

Coase (1960) indicates that agreements are not instituted in many common-property situations because costs would be too high. Fields (1989) separates costs into two categories—transactions costs among commons users and exclusion costs against outsiders. Transactions costs would result from efforts by the members to police free-riders within the cooperative who may shirk responsibilities. Costs of exclusion would be those incurred to maintain the commons boundaries from outsiders. Unless some occurrence would lead to increased demand for the product or to decreased costs of operation, a solution to the inefficiency in the fishery would not be expected without government intervention.

The impetus behind the movement toward the scallop cooperative was the increase in stocks and technological changes discussed earlier, especially those that led to an oligopsonistic structure in scallop processing, and hence to relatively much lower costs of enforcing cooperative behavior. In this environment, successful formation of the CSCA was possible.

Economies of scale limited new processor entrants to the fishery, thus holding down exclusion costs. Since there is no competition from recreational fishermen for the scallop, this exclusion cost is further reduced. Additionally, the nonmigratory nature of scallops makes property rights still more attainable for the cooperative. With the concentration of the scallops within a relatively small area, cooperation by a small number of members is further enhanced. Since all scallops caught were delivered to the CSCA processors, desired rules on harvesting could be maintained by the CSCA.

The specific mechanism was that any firm in the fishery had the right to inspect the catch of any vessel, whether being landed at its processing plant or the plant of a rival firm. It was agreed that if a random sample of 6 gallons of shucked scallop meats averaged less than 38 mm in shell size, the product, by common agreement, was to be discarded—thrown overboard. Thus, although the scallop industry was not overfished in the classic sense, this joint conservation and economic measure represents the cooperative solution.

In the first couple of weeks of the cooperative agreement, rumors of the landing of undersized product were frequent. But, the checking mechanism ended the rumors quickly. In the end, one boat captain turned himself in, and one processor turned in one of his boat captains. In each case the product was discarded. After those instances, the agreement seemed to work well, and the natural conflict among boat captains and between boat captains and processors was reduced at least to a tolerable level.

A part of the reason why the agreement worked so well is no doubt due to the fact that the CSCA did not establish the 38 mm shell size constraint. That was developed independently by a university biologist whose research was underwritten largely by the industry, but who was able to be persuasive about the rationale for the size restriction. Thus, the agreements of the CSCA were limited to these harvesting guidelines and not to other economic decisions such as a division of market share.

With the small number of CSCA members (5), costs of policing were kept low. More members in the agreement would increase the policing costs, so transactions costs would be expected to be directly related to the number of firms. Liebcap and Wiggins (1984) found that if the number of firms was less than five, private agreements could be completed successfully between firms sharing a common pool of oil. State enforcement was necessary when the number of firms rose to about 10-12.

Johnson and Libecap (1982) show that the greater the heterogeneity among firms, the higher the contracting and transaction costs will be. Although levels of operation and output vary among the CSCA members, managerial skills and processing equipment are similar for each member, and can be transferred to new members, along with quota rights. Johnson and Libecap (1982) also argue that taxes or quotas set by the government are inefficient solutions, as better fishermen will lose economic rents that they could garner through greater fishing skills.

Environmental uncertainties such as disease and migration of scallops challenge management of the fishery. This complicates determination of harvesting guidelines. Although this uncertainty will increase the costs of control to the cooperative, it can still be argued that the CSCA solution was a more desirable result than could be expected from open access and was as good as or better than could be expected from governmental regulation.

Enabling Legislation

Although the conditions under which a cooperative solution can arise are very restrictive, the conditions could be enhanced greatly by enabling legislation. The enabling legislation would allow the formation of cooperatives and provide that decisions of the duly elected cooperative member firms would be binding on all. This would allow for a cooperative solution without the need for the very unusual circumstances which fostered the CSCA.

Historically, it has been difficult to limit access to ocean fisheries, as some voluntary agreements have been seen to be violations of antitrust policy. Agreements by U.S. fishermen unions from the 1930's to the 1950's were dismantled by the Federal government as violations of the Sherman Act. Numerous legal cases brought by the canneries and excluded fishermen challenged the legality of these arrangements (Libecap, 1989).

Vertical integration, when a company operates in more than one stage of the production process, could be subject to antitrust legislation. Cooperatives have been given some exemptions in this area. Section 6 of the Clayton Act (1914) and the Capper-Volstead Act (1922) partially exempted agricultural cooperatives from antitrust restrictions. The Fisheries Cooperative Marketing Act (1934) gave a similar exemption to fishermens' organizations (Benson and Greenhut, 1986).

What would be the logical decisions that might be legislatively mandated as enforceable? Government guidelines most readily acceptable to affected parties would be ones that increase the value of the catch. Limits to the number of members, cooperative membership fees, resource opening and closing dates, gear restrictions, and harvest limits (quantity and/or size) seem the most obvious choices. Gear restrictions that allow small scallops to escape would be efficient, although if restrictions simply limit competition, this may reduce technical efficiency and thus be undesirable. If a fishery is already established, greater consideration may have to be given to guidelines, since established fishermen would prefer the status quo to permitting additional competition.

Certain attributes of the calico scallop fishery help to identify fisheries or other industries with similar management problems that would be suitable for such a cooperative approach. As mentioned, the small number of participating firms, the fact that they were in close proximity to each other, and the fact that there were no recreational fishermen all seem important. The fact that the life cycle of calico scallops is very short is also significant. One can hardly imagine prudent management of whaling by the member firms. As whales live for decades, the time horizon would be too long. No doubt other critical attributes of a successful candidate for such a management regime will occur to others.

Conclusion

A common property resource with open access, such as a fishery, will be used to excess when faced with sufficient demand. This will lead to an excessive amount of effort on the part of the fishery, dissipating scarcity rents, and resulting in depletion of the stock. The possibility of capturing these lost rents creates an incentive for fishermen to contract among themselves. Since establishing property rights is costly, the rewards for the contractors must outweigh costs.

This paper has considered the formation and enforcement of property rights which led to a gain in efficiency. The CSCA provides an example of how property rights can be assigned to a common property resource without resorting to governmental intervention. Although the scallop industry was not overfished in the classic sense, cooperative self-regulation of scallop harvesting represented an improvement over the common pool losses that would exist without controls.

The impetus behind the transformation was technological change. By internalizing the cost of regulation, resources could be allocated more efficiently, with increased productivity of the grounds and lowered costs due to economies of scale. Distribution of the gains may be controversial, requiring compensation to parties negatively affected. If the fishery had been well established before the CSCA, it would have been more difficult to achieve cooperation, as established fishermen would have preferred the status quo.

The inflexibility and ineffectiveness of much government policy makes the cooperative solution a desirable alternative. Earlier, a few examples of the failure of government regulation of fisheries were considered. Given the current deregulatory mood among policy makers (i.e., banking, airlines, trucking, etc.), which has recognized the benefits of the market incentive approach, it would be practical to consider the applicability of the cooperative as an alternative approach to regulation. By allowing groups to be self-regulating, in effect Adam Smith's self-interested individual principle can lead to gains for society.

The calico scallop fishery is a common property that lent itself to a cooperative solution, as discussed above. If costs of policing members and excluding nonmembers can be kept low, the motivation to act in a productive and collective manner can exist for similar fisheries. The government may play a role in reducing the costs of establishing rights in those fisheries that exhibit elements similar to the CSCA. For example, government officials may set the maximum sustainable yield allowed or perhaps limit the number of members. The rights to the fishery could be auctioned off to the highest bidders, whether they may be the local community or other interested parties, creating revenues that could be utilized for improvement of the resource. The government could be used in a limited manner, with the sole purpose of internalizing the costs of regulation. Clearly, it may not be feasible to provide ownership rights for all fisheries, especially those involving migratory patterns over large areas.

The economic benefits from an efficiently run operation can be considerable. With the prospect of growing resource scarcity in fisheries and substantial social welfare gains to be realized from proper management, the viability of efficient cooperatives should be further explored.

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Pacific Hagfish, *Eptatretus stouti*, and Black Hagfish, *E. deani*: The Oregon Fishery and Port Sampling Observations, 1988–92

WILLIAM H. BARSS

Introduction

Hagfish, *Eptatretus* spp., of the class Agnatha, family Myxinidae, are among the most primitive and unique of fishes. They have cylindrical eel-shaped bodies, a cartilaginous skeleton, four hearts, 10–14 pairs of gill pores, and lack scales, jaws, and paired fins. Their eyes are rudimentary, appearing as small lightly shaded areas of skin (Hart, 1973). These fish compensate for their lack of vision with keenly developed senses of smell and touch (Jensen, 1966).

The head has a single large terminal nostril, eight barbels surrounding the nostril and mouth, two parallel rows of strong, horny teeth on each side of the tongue-like dental plate, and one longer median tooth situated dorsally at the mouth opening (Dawson, 1963). Sexes are separate, and both male and female hagfish have a single gonad. During each spawning cycle, females produce a small number of large eggs, which are fertilized after extrusion (Jensen, 1966).

Hagfish have numerous glands along both sides of their body which produce copious quantities of tenacious slime when agitated or for self defense. Presence of this slime on fishing gear, such as traps and hooks, reduces the catch of other species. The slime is difficult to remove from vessels and gear. Thus, fishermen in the northeastern Pacific call hagfish "slime eels."

Hagfish behavior is also unique. They swim in a snake-like motion (Jensen, 1966). They attack hook-caught or trap-caught fish by burrowing into the fish's body to quickly devour the flesh and viscera.

Two species of hagfish are commonly found off Oregon: Pacific hagfish, *Eptatretus stouti*, and black hagfish, *E. deani*. The Pacific hagfish's body is usually gray to light brown and has a white ring around each gill pore and white along the ventral finfold. Black hagfish are usually a uniform black or dark brown and do not have a white ring around their gill pores.

Logbook records from Oregon hagfish fishermen indicate that Pacific hagfish are commonly caught at depths of 91–219 m, while black hagfish are commonly caught at depths >219 m. Cailliet (1991) reported that in Monterey Bay there was little overlap between species, but catches from 500–750 m infrequently included both species. He also stated that black hagfish were found out to depths of 1,000 m. Both species are strictly marine.

Hagfish have been observed during submersible dives off Oregon from 1987 through 1990 (Pearcy et al., 1989; Hixon et al., 1991). Hagfish were common on the muddy sea floor or in burrows. They appeared to prefer soft mud in contrast to sand. Pacific hagfish have also been observed near Vancouver Island, Can., on mud or silt substrate (McInerney and Evans, 1970). Adam and Strahan (1963) report that most species of hagfish require a bottom into which they can burrow, and that they are only found in large numbers where the bottom is covered by mud or soft sediment. Foss (1963) also reported that hagfish, *Myxine glutinosa*, have been observed entering holes on mud bottoms near Norway. Recent trap surveys and remotely operated vehicle (ROV) dives in Monterey Bay, Calif., have shown wider habitat use than previously reported, because while a majority of animals were found in sand or mud areas, a high percentage (30%) were in mixed substrate, and some occupied areas consisting only of massive substrate, (Cailliet, 1991).

Hagfish flesh is eaten in the Orient, and in recent years hagfish skins have

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ABSTRACT—In 1988, the Oregon Department of Fish and Wildlife began sampling and monitoring the development of a new fishery for Pacific hagfish, Eptatretus stouti, *and black hagfish,* E. deani. *Hagfish landings by Oregon trap vessels have ranged from 11,695 kg in 1988 to 340,774 kg in 1992. Whole frozen fish were shipped to South Korea for the "eel skin" leather market. From 1988 through 1989, I sampled 924 Pacific hagfish and 897 black hagfish from commercial and research catches. Mean length of fish sampled from commercial landings was 39.6 cm for Pacific hagfish and 34.5 cm for black hagfish. Weight-length relationships ($W=aL^b$) were calculated for males and females of both species. Fifty percent maturity for male and female Pacific hagfish was 35 cm and 42 cm, respectively, while 50% maturity for male and female black hagfish was 34 cm and 38 cm, respectively. Examination of gonads for both species indicated that spawning either occurs throughout the year or the spawning period is protracted. Mature females of both species had from one to three distinct sizes of eggs, but they usually carried only one group of eggs over 5 mm in length. Mature Pacific hagfish females averaged 28 eggs over 5 mm in length, and black hagfish females averaged 14 eggs over 5 mm in length. Hermaphroditism was found in 0.2% of the Pacific hagfish examined.*

been eagerly sought by buyers from the Republic of Korea. The skin is processed into leather "eel skin," which is used to make wallets, purses, shoes, and other articles. Demand for this leather exceeds the Asian supply. In recent years, Asian hagfish landings have declined, and Korean buyers have sought quality hagfish skins worldwide (Gorbman et al., 1990). Information on the Asian hagfish fishery, research, and management practices has been very difficult to obtain.

The U.S. west coast fishery began in 1987 following a 1986 shipment of Pacific hagfish samples from California to the Republic of Korea (Kato[1]; Hardwick[2]). In 1988, at least seven boats landed about 313,400 kg of, primarily, Pacific hagfish at Monterey, Calif. In 1989, at least 37 vessels landed about 539,000 kg in California, and fishing extended to additional California ports. Fishermen initially used small, cylindrical, plastic, baited traps manufactured in Korea, which became known as "Korean traps." Fishermen now usually use larger traps, such as 5-gallon buckets and 50-gallon drums (Barsky[3]). California fishermen use the chemical MS–222 to anesthetize the fish as soon as the traps are pulled at sea, because live fish often bite each other, damaging the skins. Some buyers set a minimum acceptable fish size of 12–14 inches (30.5–35.6 cm). Fishermen received from $0.25 to $0.50/pound ($0.11 - 0.23/kg) for whole hagfish. California required hagfish fishermen to obtain a $25 trap permit until 1992, when, following a brief period of limited entry into the fishery, the trap permit was raised to $250 per season. Hagfish traps must include a biodegradable mechanism to prevent "ghost fishing" by lost traps. Vessels are limited to using either 1,200 cylindrical traps with a maximum size of 6 inches in diameter and 24 inches long or 300 traps of any other type. Fishermen must also keep a logbook on their fishing activities.

In 1992, California briefly established a limited entry on hagfishing. Limited entry qualifications were based on landing history, and a minimum landing of 500 pounds was required during the years 1988–90. Limited entry was repealed in August 1992 owing to the lack of markets for California hagfish.

Hagfish fishing off British Columbia started in 1988 (Neville[4]). Some vessels land frozen fish while others land fresh iced fish. Buyers do not purchase fish under 12 inches (30.5 cm). Fishermen use MS–222 to anesthetize or kill their hagfish at sea. Fishermen must maintain a logbook on their fishing activities and provide Canadian biologists with data and fish samples from their catches.

Canadian hagfish permits are required for hagfish fishing, and fishing is limited to standard traps (Harbo[5]). A standard trap is a cylinder 12 cm in diameter and 60 cm long. Separate permits are issued for inshore and offshore areas . The inshore area is inside the surf line, and 8 permits are available for this area. Vessels permitted inshore are limited to a maximum of 2,000 standard traps. Eleven permits are available for offshore, and each vessel is limited to 4,500 standard traps.

In 1992, only one vessel fished for hagfish off Canada, and there was only one buyer. The vessel was allowed to fish some experimental 5-gallon traps but was also required to fish standard traps.

Washington requires a permit for hagfish fishing within the Puget Sound, and the first one was issued in 1989 (Wildermuth[6]; Culver[7]). This permit specifies the species, type of trap, number of traps, fishing area, when fishing is allowed, and reporting requirements. No landings have been made under the permit and commercial quantities of hagfish in that area are doubtful.

Hagfishing began off the Washington coast in 1991 (Culver[7]). Beginning in 1992, an experimental fishing gear permit was required for the hagfish trap fishery in Washington's ocean waters. This permit was designed after a similar permit used by Oregon. It authorizes that only hagfish can be retained from hagfish traps, and it requires biodegradable escape exits, buoys marked with permittee's buoy identification number, and logbook records on fishing activities.

Since about 1989, some hagfish fishing has also occurred off Alaska with minor landings (Paust[8]). A sustained fishery has not developed, and while black hagfish were plentiful, few Pacific hagfish were caught.

A hagfish trap fishery began off the Oregon coast in 1988. At that time, Oregon regulation for fish traps (OAR 635–04–035) required biodegradable escape panels. These panels had to provide an opening of at least 8 inches (20.3 cm) in diameter when the panel deteriorated. It was difficult for hagfish fishermen to comply with this rule, and in May 1990, the Oregon Department of Fish and Wildlife (ODFW) began issuing experimental fishing gear permits for the hagfish trap fishery. The permit authorized the use of hagfish traps approved by ODFW. An approved trap contained an escape exit of at least 3 inches (7.6 cm) diameter of qualifying biodegradable materials. All species of finfish and shellfish except hagfish caught in these traps had to be released immediately. By October 1990, 52 permits were issued. On that date, Oregon Administrative Rules were amended to authorize the use of approved hagfish traps, and permits were no longer required

Following the first Oregon hagfish landing in 1988, because of the commercial interest in hagfish and the lack of literature about basic hagfish life history, abundance, or even distribution,

[1]S. Kato. 1990. Report of the biology of Pacific hagfish, *Eptatretus stoutii*, and the development of its fishery in California. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Tiburon Lab., Tiburon, Calif. Unpubl. manuscr., 39 p.

[2]J. Hardwick. 1988. Calif. Dep. Fish Game, 2201 Garden Road, Monterey, CA 93940. Personal commun.

[3]K. Barsky. 1990, 1993. Calif. Dep. of Fish Game, P.O. Box 821, Santa Barbara, CA 93102. Personal commun.

[4]C. Neville. 1989. Dep. Fish. Oceans, Pac. Biol. Sta., Hammond Bay Road, Nanaimo, B.C. V9R 5K6. Personal commun.

[5]R. Harbo. 1993. Dep. Fish. Oceans, Fish. Branch, 3225 Stephenson Point Road, Nanaimo, B.C. V9T 1K3. Personal commun.

[6]D. Wildermuth. 1989. Wash. Dep. Fish., 7600 Sand Point Way NE, Bin C15700, Bldg. 4, Seattle, WA 98115. Personal commun.

[7]B. Culver. 1993. Wash. Dep. Fish., Coastal Lab., 331 State Hwy. 12, Montesano, WA 98563. Personal commun.

[8] B. Paust. 1989, 1993. Mar. Ext. Serv., Univ. Alaska, P.O. Box 1329, Petersburg, AK 99833. Personal commun.

ODFW began to monitor its hagfish fishery and collect the necessary data to manage its hagfish stocks and develop a sustainable commercial hagfish fishery. From October 1988 through 1991, hagfish sampling was conducted on a continuing basis to obtain an information base for sound management of the fishery and optimum use of the hagfish resource. This paper describes Oregon's hagfish fishery and summarizes the biological data that we obtained during our first 2 years of sampling hagfish.

Methods

Most data were collected from commercial trap landings at Newport and Astoria, Oreg., during the fall of 1988 and from July through December 1989. These landings represented catches off Oregon except for a single trip in November 1988 that included fish from off Crescent City and Eureka, Calif. (Fig. 1). In 1989, additional samples were obtained from the National Marine Fisheries Service through research trawl catches off Oregon made by the F/V *Golden Fleece* and by Oregon State University on the F/V *Olympic*, from incidental catches in Dungeness crab, *Cancer magister*, and sablefish, *Anoplopoma fimbria*, traps, and from experimental hagfish traps. The incidental catches and experimental trap catches came from off Oregon and off Washington immediately north of the mouth of the Columbia River.

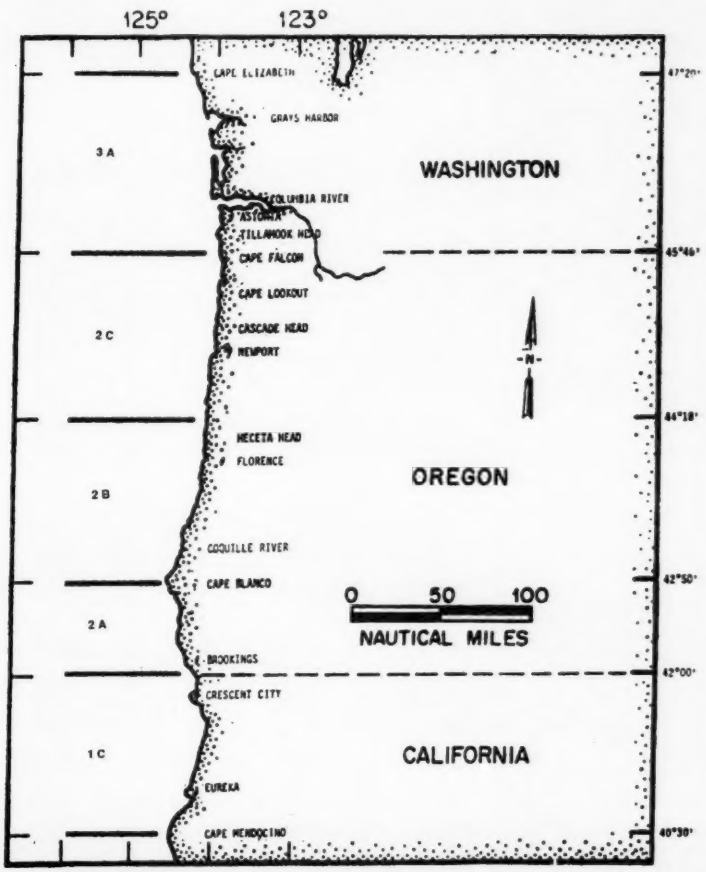

Figure 1.—Pacific coast from Cape Elizabeth, Wash., to Cape Mendocino, Calif., and Pacific Marine Fisheries Commission International Statistical Areas 3A to 1C.

Samples were obtained from two different types of commercial traps, and one of these types was modified with escape holes and used as an experimental trap. Traps were usually baited with fish frames or whole fish rejected from the trawl fishery. The most commonly used trap was the cylindrical, plastic trap known as the "Korean trap." This black-colored trap was about 53 cm in length, 11.5 cm in diameter, and contained a removable funnel-type entrance at one end. Its sides were perforated with a large number of holes of approximately 8 mm in diameter. The second type trap was used only in 1988 by one vessel. It was similar in design to the trap known as the Korean conical sablefish trap, and fishermen called it a prawn-style trap. This trap had a base diameter of about 60 cm, and was about 46 cm high. The experimental trap was the cylindrical, plastic "Korean trap" modified to contain one to two escape holes. Escape holes had diameters of 1.3 cm, 1.9 cm, or 2.5 cm. These traps were designed to test the hypothesis that traps could be made that would retain a desired size of hagfish, while also allowing small fish to escape.

I tried to sample at least one 13–18 kg box of hagfish per month from commercial landings. Hagfish from commercial landings were not usually available until they had been landed, randomly placed in shipping boxes, and frozen. A box of hagfish contained up to 300 fish, and all the fish in a box were usually sampled. I also sampled incidental hagfish catches from commercial sablefish traps, commercial crab traps, experimental traps, and research trawls.

Sorting of commercial catches was not common in 1988, but in 1989, most Oregon catches were sorted at sea by fishermen to remove unmarketable or small hagfish. Sorting did not occur on hagfish during incidental or research trawl catches.

Samples were examined at the ODFW laboratory in Newport. Data recorded for each fish examined included species, sex, and total length (cm). Most fish were also sampled for round weight (g) and stage of maturity. Data were also obtained on number of eggs, egg length (mm), and/or testis diameter (mm).

Criteria for determination of sex and maturity stage are given in Table 1. Photographs of selected maturity stages are shown in Figures 2 and 3. Gonads were not microscopically examined. Females containing eggs over 5 mm long were classified as mature. Males with round gonad follicles larger than 1 mm in diameter were classified as mature.

Two situations were used for discerning the time of spawning. First, anchor-like terminal hooks with each hook attached to the egg by a thin filament are formed at each end of a hagfish egg just before egg extrusion (Fig. 2 D). Second, a developing egg is held in a ovarian capsule, and a large empty capsule is found in the ovary for a short period of time following extrusion of the egg from that capsule (Fig. 2 E).

Sample data were summarized by species, sex, gear, and month with special emphasis on length at maturity and time of spawning.

Oregon's Commercial Hagfish Fishery

Oregon's hagfish fishery began in October 1988 when two trap vessels landed 11,695 kg at Newport. About 4,165 kg was black hagfish, and the rest was Pacific hagfish. About 60% of the catch was frozen at sea. An estimated

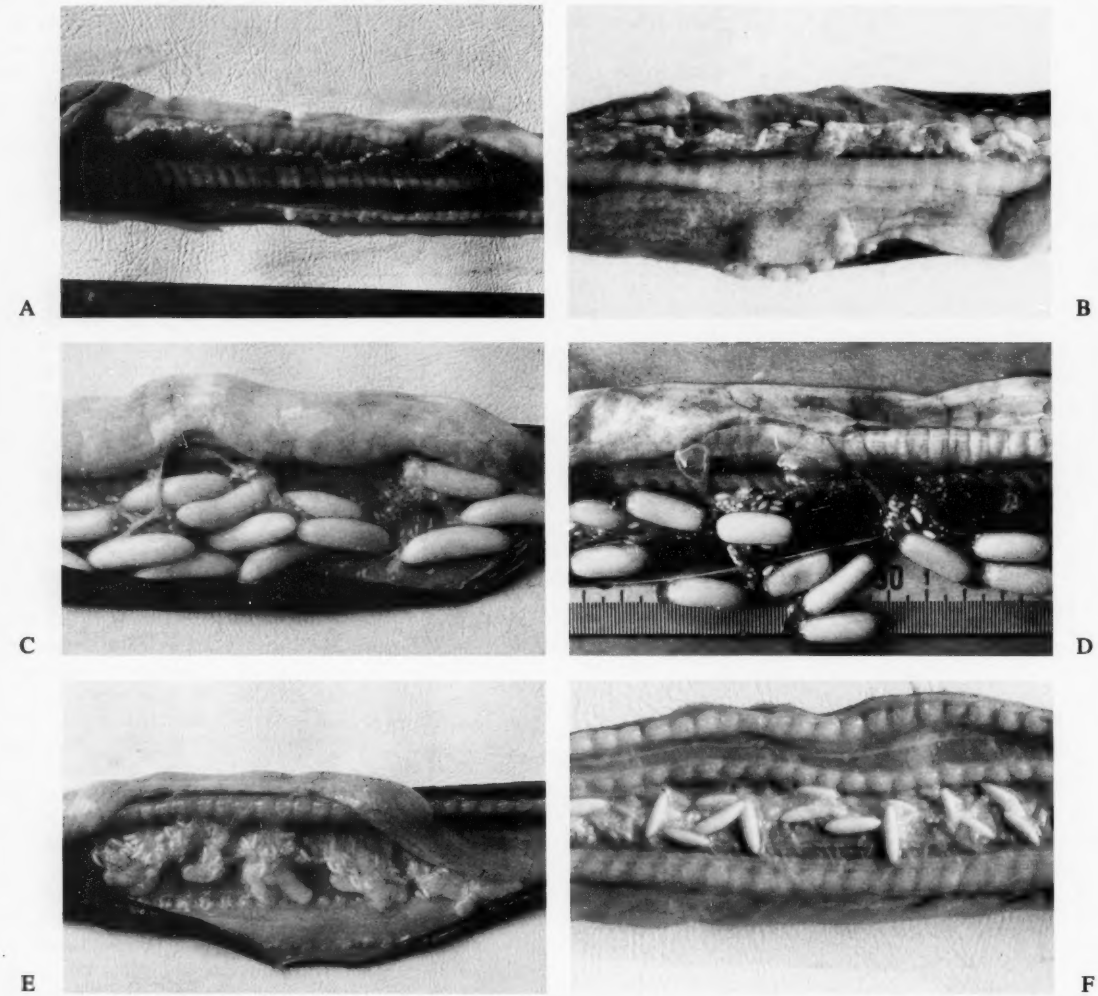

Figure 2.—Female black hagfish gonads. A) Gonad stage 1, immature female. All eggs are small (≤1 mm in length), round, and located all along the length of the gonad. B) Gonad stage 2, maturing female. There are a few oblong eggs >1 mm but <5 mm in length. C) Gonad stage 3, mature ova, developing female. Here, some eggs are >5 mm in length. D) Gonad stage 4, mature ova, developed female. Hooks are present at both ends of each large egg. E) Gonad stage 5, mature, spent female. Large empty ovarian capsules are present (as well as some small oblong eggs). F) This gonad contains three different size groups of eggs.

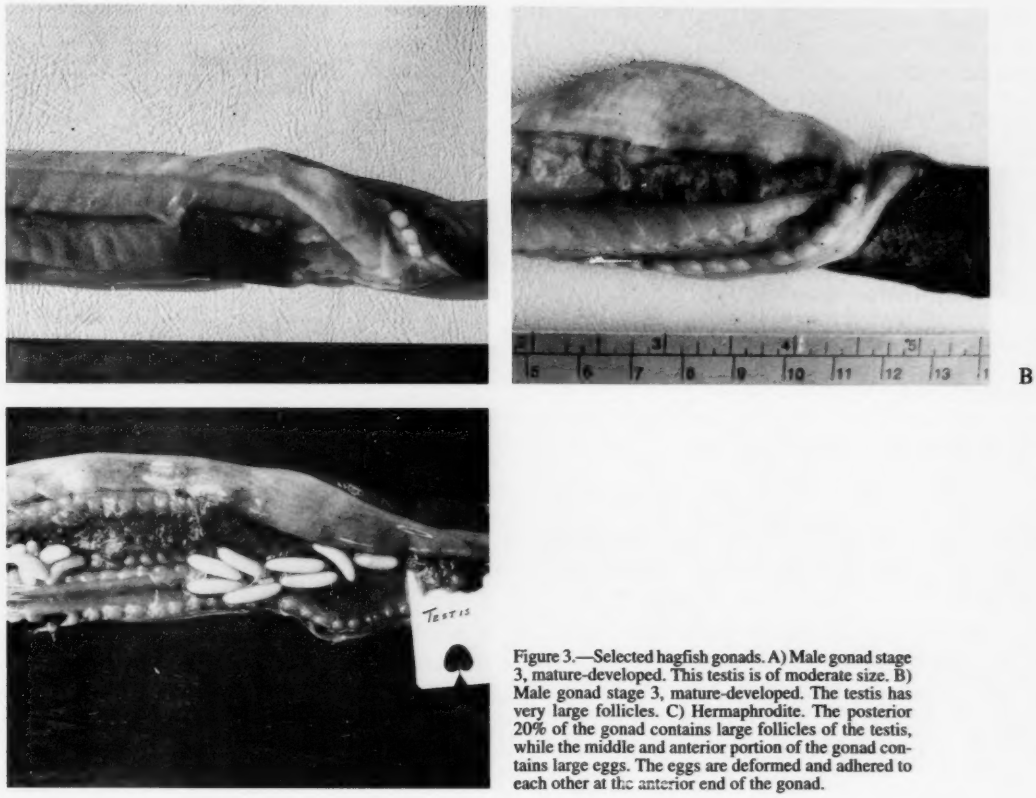

Figure 3.—Selected hagfish gonads. A) Male gonad stage 3, mature-developed. This testis is of moderate size. B) Male gonad stage 3, mature-developed. The testis has very large follicles. C) Hermaphrodite. The posterior 20% of the gonad contains large follicles of the testis, while the middle and anterior portion of the gonad contains large eggs. The eggs are deformed and adhered to each other at the anterior end of the gonad.

Table 1.—Gonad condition criteria applied to the genus *Eptatretus* from samples collected in Oregon, 1988–89[1].

Sex and stage	Condition	Criteria
Females		
1	Immature	All round eggs, ≤1 mm, eggs may appear as bubbles in anterior half of narrow (<2 mm wide) gonad
2	Maturing (not mature)	Some oblong eggs, >1 mm, but < 5 mm in length and no large empty ovarian capsules (egg sacks), may also contain some ≤1 eggs
3	Mature-ova developing	Some oblong eggs, >5 mm in length, without hooks, may also contain some ≤1 mm eggs and some >1 mm, but <5 mm eggs (exclude fish in Mature-spent condition)
4	Mature-developed	Some large eggs, >20 mm with hooks, may also contain some ≤1 mm eggs, some >1 mm, but <5mm eggs, and some >5 mm eggs without hooks
5	Mature-spent	Large empty ovarian capsules and maturing or mature eggs, may also contain some immature eggs
Males		
1	Immature	Posterior end of gonad small (about 1 mm) in width and almost colorless (slightly milky)
2	Maturing (not mature)	Posterior end of gonad with small (<1 mm diameter) round white follicles
3	Mature-developed	Posterior end of gonad with large (>1 mm diameter) round, white to brown follicles
Unknown		
1	Immature	Empty gonad, no testis or eggs observed
Hermaphrodite		
1	Hermaphrodite	Both eggs and follicles of testis present

[1] See Figure 2 for photographs of gonad condition stages for female hagfish. See Figure 3 for photographs of gonal condition stages for male and hermaphrodite hagfish.

4,838 kg of the Pacific hagfish were caught off California between Trinidad Head and the Oregon-California border. Black hagfish were caught in about 366–457 m (200–250 fm), while Pacific hagfish were usually caught on a mud substrate at a depth of about 110–183 m (60–100 fm). An estimate of catch per trap could be made on only one of the four trips using "Korean traps." That estimate was 1.4 kg of hagfish per trap.

In 1989, six vessels landed hagfish, but almost all the fish were landed by three of those vessels. Fishermen landed 156,123 kg of hagfish at Newport and Astoria (Table 2). Landings were overestimated because some landings included the weight of packaging material and peatmoss or sawdust which was commonly used in processing and handling hagfish at sea. About 40–45% of the hagfish were frozen at sea.

In 1989, the small cylindrical Korean trap produced a catch of about 0.8 kg of hagfish per trap. Usually 2,000–2,500 of this style of trap were fished (Fig. 4). Larger traps, which we were unable to measure or observe, were fished by one vessel. About 500–1,000 of these large traps were fished; they caught an average of 2.7 kg of hagfish per trap.

In 1989, fishermen targeted Pacific hagfish and avoided black hagfish by setting their traps at depths of about 55–

Table 2.—Oregon hagfish landings, 1988–92[1].

Year and month		Weight (kg)	Number of landings	Number of vessels	Year and month		Weight (kg)	Number of landings	Number of vessels
1988	Oct.	4,664	3	1	1991	Jan.	21,864	28	3
	Nov.	7,031	1	1		Feb.	8,068	7	3
						Mar.	26,175	25	4
1989	July	24,978	4	1		Apr.	29,989	33	4
	Aug.	5,321	4	2		June	8,550	11	3
	Sep.	37,375	10	3		July	2,275	4	1
	Oct.	44,255	11	6		Sep.	2,520	1	1
	Nov.	28,394	1	1		Dec.	24,066	22	4
	Dec.	14,800	1	1	1992	Jan.	30,792	34	8
						Feb.	66,112	64	10
1990	Apr.	2,828	4	2		Mar.	87,501	86	11
	May	2,049	3	2		Apr.	55,492	40	10
	July	647	2	1		May	30,960	20	8
	Aug.	16,048	24	4		June	10,316	10	5
	Sep.	9,646	16	3		July	3,752	7	3
	Oct.	4,636	8	4		Aug.	26,411	22	4
	Nov.	22,026	27	4		Sep.	18,078	16	3
	Dec.	18,063	18	3		Nov.	6,631	6	2
						Dec.	4,729	5	2

[1] Hagfish landings in August through October 1989 were gross weights, which included peatmoss or sawdust and containers.

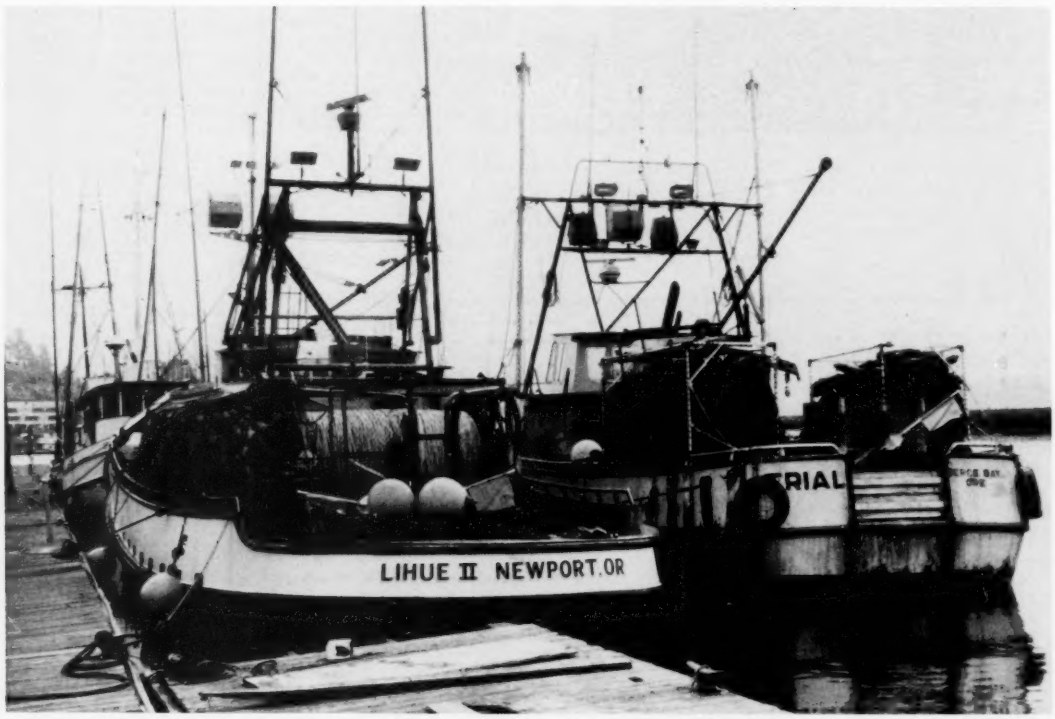

Figure 4.—F/V *Lihue II* and F/V *Trial* were two of the vessels that used the Korean traps for catching Pacific hagfish off Oregon in 1989. Fishing gear (traps, buoys, groundline, and flags) common to this fishery is on the back of the vessels.

105 fm; black hagfish were caught in only one set. That set, the deepest of the year at about 103 fm, resulted in an estimated catch of 200 pounds (91 kg) containing a mix of black and reportedly small Pacific hagfish.

In 1990, Oregon hagfish landings dropped, but since that reduction in poundage, there has been a modest increase in landings, mostly of Pacific hagfish. In 1990, 11 vessels landed 75,924 kg of hagfish from 102 trips. In 1991, 12 vessels landed 124,506 kg of hagfish from 131 trips. In 1992, 15 vessels landed 340,774 kg of hagfish from 310 trips.

Sampling Results

Samples were obtained from all four commercial landings in 1988 (360 Pacific hagfish and 635 black hagfish) and 5 of the 31 landings (428 Pacific hagfish) in 1989. In 1989, 20 samples came from incidental or research catches: 11 from trawl catches on NMFS and OSU research cruises, three from Dungeness crab traps, two from sablefish traps, and four from research traps modified with escape holes (Table 3).

Table 3.—Summary of hagfish samples taken in 1988–89.

Date	Source	Location of catch[1]	Depth (fm)	Number taken	
				Black hagfish	Pacific hagfish
10–10–88	Hagfish trap	Newport	200	220	0
10–13–88	Hagfish trap	Newport	?	304	0
10–24–88	Hagfish trap	Newport	?	111	102
11–16–88	Hagfish trap	Brookings-Eureka	63–100	0	258
01–22–89	Crab trap	Astoria	50	0	5
02–06–89	Crab trap	Astoria	55	0	32
04–05–89	Crab trap	Astoria	50	0	5
05–26–89	OSU trawl	Central Oregon	159–200	9	0
05–26–89	OSU trawl	Cape Lookout	65	0	1
06–04–89	Sablefish trap	Astoria	400–550	45	0
06–13–89	Hagfish trap[2]	Newport	210	120	0
07–03–89	OSU trawl	Cascade Head	85–119	0	2
07–08–89	Research trap	Cape Falcon	75	0	28
07–08–89	Research trap	Cape Falcon	75	0	14
07–17–89	Hagfish trap	Cape Falcon	55–75	0	106
08–18–89	Hagfish trap	Cape Falcon	62–74	0	68
09–11–89	Hagfish trap	Newport	80–86	0	100
08–04–89	NMFS trawl	Bodega Head	160	0	1
08–12–89	NMFS trawl	Oregon-Calif.	63	0	1
08–15–89	NMFS trawl	Coquille River	73	0	1
08–29–89	NMFS trawl	Tillamook Head	81	0	1
09–03–89	NMFS trawl	Grays Harbor	68	0	1
09–16–89	NMFS trawl	Heceta Head	230	26	0
09–16–89	NMFS trawl	Heceta Head	322	19	0
09–22–89	NMFS trawl	Newport	350	43	0
09–26–89	Hagfish trap	Newport	77–84	0	1
09–26–89	Hagfish trap	Newport	77–84	0	76
09–26–89	Research trap	Newport	77–84	0	11
10–10–89	Research trap	Newport	72–80	0	32
11–21–89	Hagfish trap	CF–CL	60–84	0	78

[1] Central Oregon means from Cape Lookout to Florence, Oregon-California means the border between Oregon and California, and CF - CL means Cape Falcon to Cape Lookout. Bodega Head is located just north of San Francisco, Calif.
[2] Hagfish traps were being used as bait holders inside sablefish traps.

Length

During 1988–89, seven commercial landings of Pacific hagfish were sampled for length (Table 4). Due to sorting in 1989, the length frequencies are not strictly comparable, but combining all the samples, length was 20–67 cm with a mean of 39.6 cm. Fish caught on a single trip between Brookings, Oreg., and Eureka, Calif., resulted in a sample of smaller fish with a mean length of 33.2 cm. The other six catches from Newport to Cape Lookout had a mean length of 42.7 cm.

Three commercial landings of black hagfish were sampled in 1988 (Table 5)

Table 4.—Length frequency distributions for Pacific hagfish sampled from commercial landings in Oregon, 1988–89[1] (M = male; F = female).

Total length (cm)	Date landed: 10-24-88		11-16-88		7-17-89		8-18-89		9-11-89		9-26-89		11-21-89	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F
20				1										
21				0		2								
22				5		0								
23			1	6		1							1	
24		3	2	7		3				1			0	
25		1	1	11		3				0			0	
26		0	4	7		5				1			0	
27		1	1	6		2				0			0	
28		4	0	7		3				0			0	
29		5	4	8		2				1			0	
30		5	2	12		0				0			0	
31		5	1	11		1				0			0	1
32		8	5	8		3				0			1	0
33	1	4	2	6		3				0			0	1
34	1	4	4	9		2				1	1		1	0
35	0	3	4	5		0			1	0	0		1	0
36	0	7	2	5	1	1		1	0	0	0	1	1	2
37	1	2	3	10	4	2		0	0	1	0	0	0	1
38	1	3	3	4	0	1	1	1	0	2	0	2	1	0
39	1	1	3	5	3	1	0	0	1	4	0	2	0	1
40	2	2	1	4	0	1	1	0	2	1	3	4	0	2
41	3	5	1	3	2	3	2	1	1	0	1	2	2	3
42	0	3	2	6	0	1	0	1	3	3	1	1	1	0
43	0	1	0	4	1	3	0	2	2	6	2	2	0	0

Total length (cm)	Date landed: 10-24-88		11-16-88		7-17-89		8-18-89		9-11-89		9-26-89		11-21-89	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F
44	0	3	2	1	1	2	1	1	0	7	3	3	4	4
45	0	1	3	2	2	4	0	0	1	6	0	7	1	4
46	0	0	0	2	3	0	0	2	0	10	6	5	1	2
47	2	1	1	2	2	4	2	1	3	10	2	2	4	5
48	1	2		0	1	0	5	3	0	4	0	2	2	2
49		1		1	1	1	4	1	1	8	3	2	0	5
50		0			0	2	1	2	1	5	1	4	2	2
51		0			1	3	0	2	1	3		3	1	2
52		1			1	2	4	2	0	2		1	1	4
53					3	2	3	0	1	0		2	0	1
54					3	0	1	3	0	1		1	1	2
55					2	0	5	0	1	0		0	1	2
56					0	1	3	0	0	0		2	1	1
57					1	2	2	1	0	0		0	1	0
58					2	0	0	0	0	0		2		0
59						0	3	0	1	0		0		1
60						1	1	0		1		0		1
61						1	2	0				0		
62								0				0		
63								0				1		
64								0						
65								0						
66								0						
67								1						

[1] Table excludes hagfish whose sex was not determined.

and none in 1989. Length was 20–52 cm with a mean of 34.5 cm.

Experimental (research) traps were fished too infrequently to test our hypothesis that traps with escape holes of a certain size could allow escapement of small hagfish while retaining large hagfish. The research traps were used by commercial fishermen who provided samples from about five traps. Total catch was only 57 Pacific hagfish with a mean size of 42.7 cm from traps with 1.9 cm-diameter escape holes and 28 fish with a mean size of 42.8 cm from traps with 1.3 cm-diameter escape holes. In July 1989, fishermen unsuccessfully attempted to catch Pacific hagfish with traps with 2.5 cm diameter holes.

Weight-Length

I used a simple regression of paired lengths and mean weights at length in the form of $\log_{10}$ length (cm) against $\log_{10}$ weight (g) to determine the weight-length relationship $W = aL^b$ (Table 6). No weight corrections were made for either state of gonad maturity or amount of food contained in the gut. The regression had a high r^2 value of 0.972083 to 0.991506. Black hagfish were slightly heavier than Pacific hagfish at the same length.

Maturity

It was difficult to determine the sex of many fish under 30 cm long, although fish as small as 20 cm had gonads that often contained granular material, which appeared to be tiny eggs. Consequently, the sex ratio was based on only mature fish, since small, immature fish could not always be sexed. The 5 mm egg length minimum size for mature females and minimum testis diameter of 1 mm for mature males was arbitrary. Small, immature females had ovaries with round eggs under 1 mm long, or ovaries contained material with a bubble-like or granular appearance. Eggs larger than 1 mm were oblong. Most large females contained eggs longer than 5 mm, whereas, the smallest females did not (Fig. 5). Most hagfish with large eggs or which had recently spawned (indicated by the presence of large empty ovarian capsules) contained at least one additional size group of eggs with an average length <5 mm. Testes did not show much obvious physical change in color or texture until around 1 mm in diameter; the testis of large males was usually at least 1 mm in diameter.

Hagfish sampled from commercial landings in Oregon were often mature, and the percentage of mature fish increased in 1989 over that observed in 1988. Mature Pacific hagfish were 26% of the sampled catch in 1988 and 69% in 1989. Although few commercial landings of black hagfish have been landed in Oregon, samples collected in 1988 contained 40% mature fish. In 1989, a sample was obtained from small cylindrical, commercial traps which were used as bait holders in sablefish traps. About 48% of the black hagfish caught in these traps were mature.

Table 5.Length frequency distributions for black hagfish sampled from commercial landings, 1988 (M = male, F = female, U = sex not determined).

	Date landed								
Total length (cm)	10–10–88			10–13–88			10–24–88		
	M	F	U	M	F	U	M	F	U
20						2			
21						1			1
22						4			0
23	5					3			0
24	2	1				9		1	0
25	5	1	1			10		2	0
26	5	1	2			6		1	1
27	6	2	0			13		3	0
28	8	6	0			12		4	2
29	5	3	0			14		1	0
30	4	6	1			15	1	4	2
31	7	6				11	1	2	
32	10	2				11	1	4	
33	7	1				16	1	2	
34	10	4				18	4	0	
35	5	5				19	2	5	
36	10	9				20	4	5	
37	4	6				23	4	2	
38	3	14				19	5	0	
39	4	7				16	7	4	
40	6	7				15	1	7	
41	0	9				15	1	8	
42	1	4				13	3	6	
43	1	3				10		1	
44	1	6				3		2	
45		0				2		3	
46		4				3		1	
47						1		0	
48								1	
49								0	
50								0	
51								0	
52								1	

Table 6.—Weight and length characteristics by species and sex for Oregon hagfish samples from Oct. 1987 to Oct. 1988.

	Weight-length characteristics			
Species and sex	Intercept	Slope	$W = aL^b$	r^2
Pacific hagfish, male	–2.215851	2.65009	$W = 0.006084L^{2.65009}$	0.984246
Pacific hagfish, female	–2.296721	2.68130	$W = 0.005050L^{2.68130}$	0.991506
Black hagfish, male	–2.443552	2.80513	$W = 0.003560L^{2.80513}$	0.981467
Black hagfish, female	–2.737398	2.99399	$W = 0.001831L^{2.99399}$	0.972083

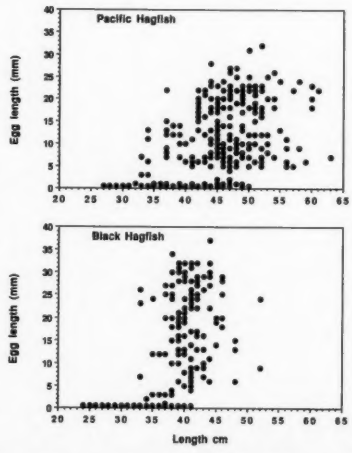

Figure 5.—Average length of hagfish egg group (largest size group of eggs) by fish length from samples of Oregon commercial landings, 1988–89.

Males comprised 30% of the mature Pacific hagfish and 39% of the mature black hagfish. The smallest mature male Pacific hagfish was 26 cm long. Almost all mature males were over 32 cm, while 50% and 100% maturity were 35 cm and 42 cm, respectively (Table 7). The smallest mature Pacific hagfish female was 30 cm long; 50% and 100% maturity were 42 cm and 51 cm, respectively. The smallest mature male black hagfish was 28 cm long, and 50% and 100% maturity were 34 cm and 41 cm, respectively. Female black hagfish first matured at a length of 33 cm, and 50% and 100% maturity were 38 cm and 42 cm, respectively.

Table 7.—Length and percent maturity for hagfish by species and sex from samples collected in Oregon, October 1988 through October 1989 (M = male, F = female).

Length (cm)	Percent mature			
	Pacific hagfish		Black hagfish	
	M	F	M	F
26	25.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0
28	0.0	0.0	11.1	0.0
29	0.0	0.0	14.3	0.0
30	0.0	5.9	16.7	0.0
31	0.0	0.0	30.0	0.0
32	20.0	5.3	35.7	0.0
33	33.3	21.4	36.4	50.0
34	42.9	27.8	58.8	0.0
35	60.0	20.0	78.9	0.0
36	60.0	18.8	81.8	33.3
37	50.0	40.0	81.0	47.1
38	83.3	21.4	72.7	63.6
39	62.5	50.0	87.5	68.0
40	77.8	28.6	76.9	88.9
41	75.0	41.2	100.0	94.3
42	100.0	62.5	100.0	100.0
43	100.0	54.5	50.0	100.0
44	100.0	77.8	100.0	100.0
45	100.0	73.1	100.0	100.0
46	100.0	89.5	100.0	100.0
47	92.3	91.7		100.0
48	100.0	90.9		100.0
49	100.0	94.1		100.0
50	100.0	92.9		100.0
51	100.0	100.0		
52	100.0	100.0		100.0
53	100.0	100.0		
54	100.0	100.0		

Time of Spawning

Sampling of Pacific hagfish was conducted during most months of the year for egg length, presence of hooks on eggs, and presence of large empty egg capsules to determine spawning time(s).

Pacific hagfish females with large eggs or empty egg capsules were found throughout the year, and hooks were noted in July (Table 8). This suggests that some spawning occurs throughout the year. Sampling of black hagfish females was conducted only during months of May through October. Large eggs, hooks, and empty egg capsules were found throughout this period (Table 9).

Egg Characteristics

Mature Pacific and black hagfish females often contained more than one size group of eggs and sometimes had three distinct size groups of eggs (Fig. 2F). Usually only one size group of eggs were over 5 mm long in a female, although there were exceptions. For example, contained throughout a single gonad, one could find one size group of eggs ranging in length from 19 to 22 mm, a second size group of eggs ranging from 1 to 4 mm, and a third size group of eggs <1 mm long. An ovary often contained over 200 eggs <1 mm long, but the number of eggs >5 mm was relatively low.

Pacific hagfish females contained up to 76 eggs that were >5 mm long, but the average was about 28 eggs. The average egg length for eggs >5 mm was 14.3 mm, with a maximum egg length of 32 mm. Black hagfish females contained up to 42 eggs >5 mm long, and the average was about 14 eggs over 5 mm long. The average egg length for eggs >5 mm was 21.4 mm, with a maximum egg length of 38 mm. There did not appear to be a strong correlation between length of mature females and number of eggs >5 mm long for either species (Table 10).

Hermaphroditism and Abnormal Gonads

Two (0.2%) Pacific hagfish were obviously hermaphroditic, while none of the 897 black hagfish sampled appeared to be a hermaphrodite. One Pacific hagfish hermaphrodite was 53 cm long, and contained a well developed testis and five large, apparently deformed eggs. The length of the eggs ranged from 10 to 15 mm. The fish also contained 14 wide, empty egg capsules that were about 8 mm long. An empty, wide egg capsule suggests that an egg was recently released from the capsule. The second hermaphrodite was 49 cm long with 13 eggs between 17 and 21 mm long (Fig. 3B). One additional egg was 8 mm long. Five of the eggs were abnormally shaped and stuck together at the anterior end of the gonad. The tes-

Table 8. — Average egg length by month for Pacific hagfish females from Oregon landings, 1988 through October 1989[1].

Egg length (mm)	Number of females											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
5–0	1	1		0			9	9	40	9	15	
11–15	0	4		0			6	0	12	1	18	
16–20	2	4		1			12	8	20	1	5	
21–25	0	1		0			5	3	26	6	2	
26–30	0	1		0			4	1	1	0	0	
>30	0	0		0			2	0	0	0	0	
Total number of fish with eggs >5 mm	3	11		1			38	21	99	17	40	
Number of fish with empty egg capsules	0	4		0			11	3	29	4	0	
Number with eggs with hooks	0	0		0			3	0	0	0	0	

[1] Table excludes observations on eggs <5 mm long.

Table 9.—Average egg length by month for black hagfish females from Oregon landings, 1988 through October 1989[1].

Egg length (mm)	Number of females											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
5–0					0	8			4	10		
11–15					0	10			7	9		
16–20					0	9			9	10		
21–25					1	11			7	10		
26–30					1	16			14	8		
>30					0	5			12	6		
Total number of fish with eggs >5 mm					2	59			53	53		
Number of fish with empty egg capsules					0	11			12	0		
Number with eggs with hooks					1	0			2	2		

[1] Table excludes observations on eggs less than 5 mm long.

tis was large and located in the posterior 20% of the gonad.

Female hagfish usually contained eggs throughout the entire length of their gonad, while in males the testis was usually located at the posterior quarter of the gonad, although there were exceptions. At least three Pacific hagfish (42–51 cm in total length) and one black hagfish (39 cm) contained a large testis (4–6 mm wide bundles) at the posterior half of the gonad and somewhat smaller testis bundles scattered throughout the anterior half of the gonad.

Table 10.—Average number of eggs >5 mm and average egg length compared to total fish length for Pacific hagfish and black hagfish, 1988–89[1].

Total fish length (cm)	Pacific hagfish			Black hagfish		
	No. of fish	Avg. no. of eggs	Avg. length of eggs (mm)	No. of fish	Avg. no. of eggs	Avg. length of eggs (mm)
33	2	11.0	12.5	3	11.7	18.3
34	3	17.3	10.3	0		
35	0			2	18.5	18.0
36	1	11.0	5.0	4	13.8	18.5
37	6	17.8	12.8	5	8.6	23.2
38	3	15.0	12.7	15	10.6	22.4
39	7	21.1	10.1	17	14.8	18.8
40	4	37.0	9.8	20	11.9	20.7
41	6	18.8	11.5	29	15.0	21.5
42	10	18.0	16.1	16	14.8	22.7
43	12	26.6	14.1	17	15.3	22.7
44	12	22.1	13.9	13	11.6	24.7
45	13	26.1	15.1	8	12.8	24.8
46	14	27.9	13.8	9	16.5	22.1
47	21	23.9	16.7	2	15.0	19.5
48	10	22.6	11.8	4	19.5	9.8
49	16	31.1	14.5	1	19.0	8.0
50	12	29.8	16.5	1	30.0	9.0
51	11	28.9	17.5	0		
52	8	32.6	16.1	2	26.5	16.5
53	6	49.3	15.8			
54	5	30.6	22.0			
55	3	49.0	9.7			
56	4	34.8	15.8			
57	3	25.7	16.3			
58	5	53.0	15.4			
59	0					
60	4	33.5	17.8			
61	2	34.0	20.0			
62	0					
63	1	20.0	7.0			
64	1	33.0	16.0			
65	0					
66	0					
67	1	57.0	10.0			

[1] Table excludes eggs less than 5 mm in length.

Discussion

Oregon hagfish landings have shown a modest upward trend with peak landings in 1992. Fishermen have produced good catches of both Pacific and black hagfish. Korean "eelskin" buyers continue to show interest in Pacific hagfish for their skins when Asian hagfish availability is down and the quality of U.S. west coast hagfish skins is good. Good quality now means "fresh" skins that have few bite marks or other damage. Fresh skins usually means live fish or fish frozen at sea. There is no apparent market at present for either black hagfish skin or the edible flesh of either species.

While hagfish appear to be plentiful off the Oregon coast, no estimate of abundance has been made. Without such data, if the fishery intensifies, overfishing could occur. This has happened off the coast of the Republic of Korea (Gorbman et al., 1990). An additional concern is that if the hagfish fishery continues to be primarily for skins, quality skins must be produced by fishermen or production may be wasted.

The Oregon Department of Fish and Wildlife will continue to require fishermen to maintain logbooks to track fishing catch and effort, and will continue to take samples of commercial landings. Age determination of our samples would provide important information, but presently no reliable aging technique has been determined. Age determination is difficult because hagfish lack scales or bony body parts,

which are usually used to age fish. Fish tagging or marking studies would be useful in determining hagfish longevity and growth rates.

Hagfish sampled from commercial landings in Oregon were often mature, though some landings have contained large quantities of immature fish. Fewer small fish were delivered after July 1989, probably due to sorting at sea to accommodate buyer preference or requirement for fish over 35.6 cm. Market requirements should provide some protection of immature fish in the future and provide an incentive to the industry to develop size selective-traps. A 38 cm minimum size limit for hagfish would insure that a portion of the populations of both Pacific and black hagfish have a chance to spawn.

Our data should be used with caution, because it does not represent the entire Oregon hagfish population. Port sampling, which was the source of most of our samples, has inherent limitations. Some small fish were probably able to escape from the traps, and some small fish were discarded. Samples were often taken after sorting, so they may not represent true population characteristics with regard to average size, size at first maturity and abundance with regard to size. Commercial fishing did not occur in all areas occupied by hagfish.

Although I was not able to sample hagfish in all months, my observations agree with those of Cailliet (1991) who found that neither sex or species showed seasonal patterns in spawning, and also those of Gorbman (1983) and Walvig (1963) who suggest that most species of hagfish spawn throughout the year. My observations also agree with the findings of Gorbman (1983) and Jensen (1966) who concluded that Pacific hagfish have a low fecundity and produce an egg series or clutch of around 20–30 eggs. I also agree with Cailliet (1991) and Gorbman (1983) that hermaphroditism is rare for Pacific hagfish. It appears that hermaphroditism is even less frequent in black hagfish, as was reported by Cailliet (1991).

I have observed hagfish[9] from submersibles in depths of 124–221 m. This coincides with fishery data from logbooks maintained by Oregon hagfish fishermen who indicate that Pacific hagfish are common in 119–219 m primarily on soft substrate. Most of the fish that I observed were identified as Pacific hagfish, *E. stouti*, and they were observed with their heads protruding out of holes in the mud, coiled on mud, and slowly moving along substrate consisting of mud or muddy sand. They were less commonly seen on mixed cobble and small boulder where they were sometimes found partially under rocks and sponges (Fig. 6).

Several management options might help prevent overfishing. Gear restrictions might include limits to the number and size of traps per vessel. There is probably a maximum number of traps that can be tended within a reasonable soak period to insure quality fish. Fishermen report that hagfish bite one another when crowded or under stress, and some fishermen and buyers recommend a short soak time of around 4 hours. Limited entry into the hagfish fishery might help prevent overfishing while also ensuring that an adequate share of

[9] Personal observation from submersibles *Delta* and *Mermaid II* off the Oregon coast, Sept. 1988, Sept. 1989, Sept. 1990, and Sept. 1991.

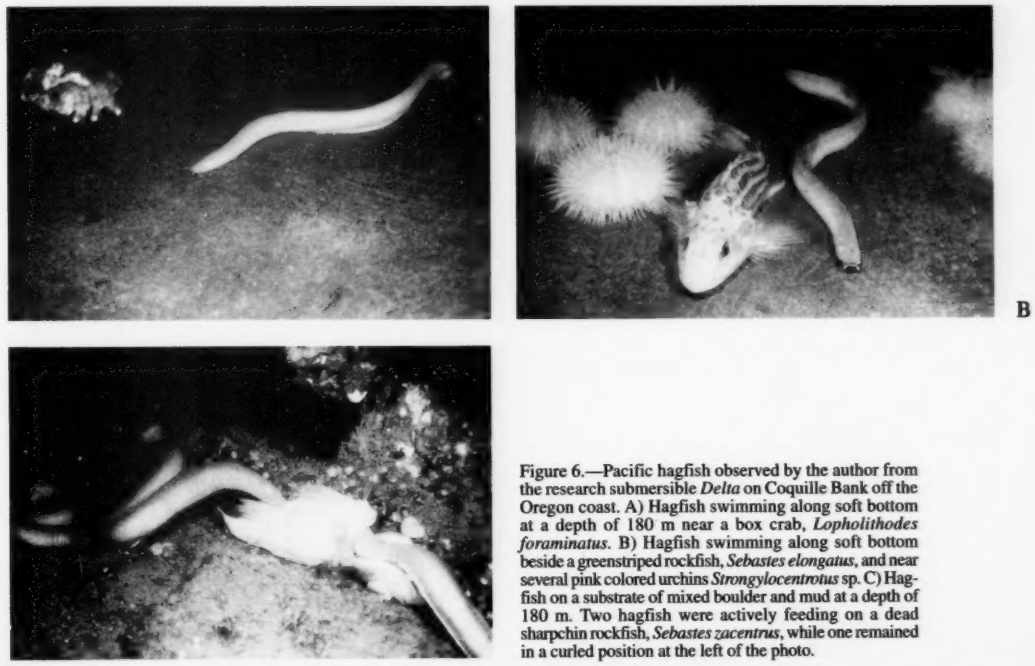

Figure 6.—Pacific hagfish observed by the author from the research submersible *Delta* on Coquille Bank off the Oregon coast. A) Hagfish swimming along soft bottom at a depth of 180 m near a box crab, *Lopholithodes foraminatus*. B) Hagfish swimming along soft bottom beside a greenstriped rockfish, *Sebastes elongatus*, and near several pink colored urchins *Strongylocentrotus* sp. C) Hagfish on a substrate of mixed boulder and mud at a depth of 180 m. Two hagfish were actively feeding on a dead sharpchin rockfish, *Sebastes zacentrus*, while one remained in a curled position at the left of the photo.

the resource is available for participants and helping to reduce the possibility of overcapitalization in the fishery.

Limiting the number of traps, length of groundline in the fishery, and the time of fishing could help lessen gear conflicts between the hagfish fishery and other fisheries. Hagfish trap fishing has the potential of preempting grounds that are also used by fishermen using different gear such as trap, trawl, troll, and longline. Reilly (1983) mentioned that trawlers generally move out of areas when crabbing occurs due to the hazard presented to their gear by crab traps. Hagfish fishermen have reported that they can avoid most gear conflicts with shrimp trawlers by fishing at night, when shrimping does not occur.

Holes in traps that allow the escape of small hagfish would reduce the amount of sorting at sea for marketable sized fish and may help protect a portion of the spawning population. Size-selective traps must permit an economically adequate catch of large hagfish. Melvin and Osborn (1992) report that larger hagfish can be selected by using larger escapement holes in traps. They compared traps with escape hole sizes of 0.38, 0.42, 0.45, and 0.48 inches. Traps with 0.48-inch escapement holes best selected for hagfish ≥12 inches in length (over 90%). When these traps were fished for 24 hours, there was a reduction of hagfish/trap catch from 104 in traps with 0.38 inch holes to 44 fish in traps with 0.48 inch holes.

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Editorial Guidelines for the *Marine Fisheries Review*

The *Marine Fisheries Review* publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

The Manuscript

Submission of a manuscript to *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under a completed NOAA Form 25-700.

Manuscripts must be typed (double-spaced) on high-quality white bond paper and submitted with two duplicate (but not carbon) copies. The complete manuscript normally includes a title page, a short abstract (if needed), text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). Manuscript pages should be numbered and have 1½-inch margins on all sides. Running heads are not used. An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

Abstract and Headings

Keep titles, heading, subheadings, and the abstract short and clear. Abstracts should be short (one-half page or less) and double-spaced. Paper titles should be no longer than 60 characters; a four- to five-word (40 to 45 characters) title is ideal. Use heads sparingly, if at all. Heads should contain only 2-5 words; do not stack heads of different sizes.

Style

In style, the *Marine Fisheries Review* follows the "U.S. Government Printing Office Style Manual." Fish names follow the American Fisheries Society's Special Publication No. 12, "A List of Common and Scientific Names of Fishes from the United States and Canada," fourth edition, 1980. The "Merriam-Webster Third New International Dictionary" is used as the authority for correct spelling and word division. Only journal titles and scientific names (genera and species) should be italicized (underscored). Dates should be written as 3 November 1976. In text, literature is cited as Lynn and Reid (1968) or as (Lynn and Reid, 1968). Common abbreviations and symbols such as mm, m, g, ml, mg, and °C (without periods) may be used with numerals. Measurements are preferred in metric units; other equivalent units (i.e., fathoms, °F) may also be listed in parentheses.

Tables and Footnotes

Tables and footnotes should be typed separately and double-spaced. Tables should be numbered and referenced in text. Table headings and format should be consistent; do not use vertical rules.

Literature Cited

Title the list of references "Literature Cited" and include only published works or those actually in press. Citations must contain the complete title of the work, inclusive pagination, full journal title, and the year, month, volume, and issue numbers of the publication. Unpublished reports or manuscripts and personal communications must be footnoted. Include the title, author, pagination of the manuscript or report, and the address where it is on file. For personal communications, list the name, affiliation, and address of the communicator.

Citations should be double-spaced and listed alphabetically by the senior author's surname and initials. Co-authors should be listed by initials and surname. Where two or more citations have the same author(s), list them chronologically; where both author and year match on two or more, use lowercase alphabet to distinguish them (1969a, 1969b, 1969c, etc.).

Authors must double-check all literature cited; they alone are responsible for its accuracy.

Figures

All figures should be clearly identified with the author's name and figure number, if used. Figure legends should be brief and a copy may be taped to the back of the figure. Figures may or may not be numbered. Do not write on the back of photographs. Photographs should be black and white, 8 × 10 inches, sharply focused glossies of strong contrast. Potential cover photos are welcome, but their return cannot be guaranteed. Magnification listed for photomicrographs must match the figure submitted (a scale bar may be preferred).

Line art should be drawn with black India ink on white paper. Design, symbols, and lettering should be neat, legible, and simple. Avoid freehand lettering and heavy lettering and shading that could fill in when the figure is reduced. Consider column and page sizes when designing figures.

Finally

First-rate, professional papers are neat, accurate, and complete. Authors should proofread the manuscript for typographical errors and double-check its contents and appearance before submission. Mail the manuscript flat, first-class mail, to: Editor, *Marine Fisheries Review*, Scientific Publications Office, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., Bin C15700, Seattle, WA 98115.

The senior author will receive 50 reprints (no cover) of his paper free of charge and 50 free copies are supplied to his organization. Cost estimates for additional reprints can be supplied upon request.

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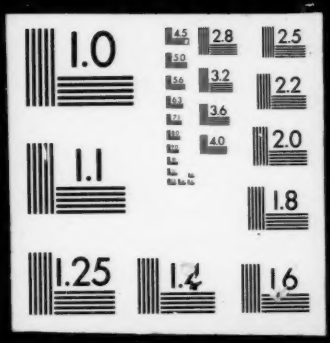
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